EARTH AND ROCK EXCAVATION.

A

PRACTICAL TREATISE.

BY

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WITH TABLES AND MANY DIAGRAMS AND ENGRAVINGS.

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PREFACE.

THERE is hardly a class of engineering construction into which excavation of earth or rock does not enter to some extent, and in many engineering works excavation is by far the largest item of labor and expense. Despite these facts English engineering literature is almost barren of books which treat of earth and rock excavation in a concise and comprehensive manner having regard both for the planning and computation of such work and for the methods and machines by which it is accomplished. The present book is an attempt to supply this deficiency and has been written with the following objects chiefly in view: First to concentrate in a small volume descriptions of the different operations which are required for planning and executing any work of excavation in either earth or rock; second, to classify and describe clearly the various implements and machines used for excavating and hauling away the material. So far as the author knows, there is no book in the English language which covers these fields.

The contents of the book, briefly summarized, comprise first a discussion of the graphical repr sentation and calculation of earthwork. This section is followed by chapters describing the construction and operation of the various machines used for excavating and transporting earth and rock. Succeeding chapters consider the various methods of planning and executing works of excavation, and describe methods for deducing the cost of such work in any particular case. A concluding section describes briefly a number of large works of excavation. For his information

regarding the various excavating machines the author is indebted to the manufacturers and to the engineering periodicals and society transactions. He has also consulted the various foreign works on excavation, and wherever foreign practice has seemed to offer suggestions of value to American engineers they have been taken. While the book is designed primarily for the student and young engineer, it contains much information that is valuable to the practicing engineer and contractor and which is not to be found elsewhere in one place convenient for consultation and use.

So far as was possible the author has given credit in the pages of the book to those who have aided him with advice and information. It is with a feeling of sincere gratitude that the author acknowledges the kindness of the different manufacturers who furnished him with the details of the methods and machines which are described herein, and he wishes to extend hearty thanks to all who have aided him in any way in the work.

CHARLES PRELINI.

CONTENTS.

EARTH AND ROCK EXCAVATION.

CHAPTER I.

THE GRAPHICAL REPRESENTATION OF EARTHWORK; PLANS AND PROFILES.

THE first operation required when any engineering work is undertaken is the preparation of plans representing accurately the labor to be performed; such plans are absolutely essential in estimating the cost of the work. In prosecuting earthwork accurate and legible plans are particularly necessary. Earthwork comprises two operations—the cutting down of the elevations projecting above the level of the proposed surface, and the filling up of the hollows lying below the proposed surface. These operations are known as cutting and filling, and the works themselves are called cuts and fills. The preparation of plans for earthwork, therefore, consists in representing graphically on paper the depths and locations of the cuts and fills.

To represent graphically the cuts and fills of earthwork it is usual either to refer the proposed surface to the original ground-surface, or else to refer both the original and the proposed surfaces to an imaginary horizontal plane located below the lowest point of either. This is called the datum plane and is used in all the leveling operations connected with the work. Three forms of representation are employed: the first is known as the method of marked points; the second, as the method of contour-lines; and the third, as the method of profile and cross-sections. Generally the method of marked points and that of contour-lines are em-

ployed where the work occupies an area of considerable width as compared to its length, and the method of profile and cross-sections where the work occupies an area which is narrow as compared to its length. Whichever method is employed, the plan must be so legible that it will be easily understood by the constructor, his superintendent, or even by the foremen on the work. These persons are presupposed to be able to read such plans and comprehend their stipulations and directions.

Method of Marked Points.—To represent earthwork by means of marked points a map or plan of the original ground-surface occupied by it is first prepared. On this map a greater or less number of fixed points are marked. These points may be either the salient points formed by the natural surface, or they may be artificial points located by transit and marked by stakes. Each point is inscribed with a numeral showing its vertical distance from the proposed surface of the earthwork, this numeral being preceded by a minus sign if the distance is above the proposed surface, and by a plus sign if the distance is below that surface. Thus the mark $+5$ will mean that the original surface is to be raised 5 ft. by filling, and the mark -5 that the original surface is to be lowered 5 ft. by cutting.

An alternative form for representing earthwork by means of marked points is as follows: A datum plane is chosen and each fixed point is marked by two numerals, one in black ink showing the altitude of the original ground-surface above the datum plane, and one in black ink underlined, or, preferably, in red ink, showing the altitude of the proposed surface above that plane. In this double notation a cut is indicated if the underlined or red-ink numeral is smaller than the black-ink numeral; and, on the contrary, a fill is indicated when the underlined or red-ink numeral is greater than the black-ink numeral. The difference between the numerals shows the depths of cut or fill in each case. Thus if we have a point bearing the numbers 37 and $\underline{42}$, we know that the original ground-surface is lower than the proposed surface by an amount equal to $\underline{42}-37=5$, and, therefore, that a 5-ft. fill is required. This form of representing

earthwork, although very simple, is seldom used in this country except for small excavations where great accuracy is required, as in foundations for tall buildings, but it is extensively used in Europe.

Method of Contour-lines. — Contour-lines are lines joining points of equal elevation on the ground-surface. They may be conceived as being formed by horizontal planes placed at regular vertical intervals apart and intersecting the ground-surface; the line where each plane cuts the ground-surface is the contour-line at that elevation or level. These planes of uniform level are usually taken at elevations 5 ft. or 10 ft. apart, but may be taken at much closer intervals, and the contour-lines formed by them show definitely the conformation of the ground. If we, therefore, plot on a plan of the site of the proposed earthworks first the contour-lines of the original ground-surface and second those of the surface of the proposed work, we have then clearly indicated the location and depths of the required cuts and fills. For example, if a line of the first series at the 20-ft. level is crossed by the 22-ft.-level line of the second series, it indicates that at the point of intersection the original surface must be raised 2 ft. to obtain the proposed surface, or, in other words, that a 2-ft. fill is necessary. On the contrary, if the 20-ft. line of the first series is crossed by the 18-ft. line of the second series, it indicates that a 2-ft. cut is required. In plotting these two sets of contour-lines on the plan the set referring to the proposed surface of the work is usually distinguished by being drawn in colored ink; usually red ink is used. The contour-line method of representing earthwork is employed particularly for works like reservoirs, drainage, irrigation, and the improvement of submerged or tidal lands. Such a plan is of great use in locating and making rough estimates of the cost of canals, roads, and railways; but in this country it is seldom employed for the accurate location and calculation of such works.

Method of Profile and Cross-sections. — The most commonly employed method of representing earthworks is by a longitudinal profile and cross-sections. This method is particularly con-

venient for representing works which are of small width and great length, such as roads, canals, and railways. The fixing of the axes of these works is a separate task, and it will not be discussed in this book except to note that it should be the result of a careful study of the technical, economical, and other conditions of the route. The axis of the work when once decided upon is marked on the ground with stakes spaced 100 ft. apart and numbered progressively from the starting bench-mark or monument. The longitudinal profile is the line formed by the intersection of a vertical plane through the axis with the surface of the ground. Cross-sections are formed by vertical planes at right angles to the axis and are usually taken 100 ft. apart or at every stake marking the axis. The profile and cross-sections together give when plotted on paper a clear graphical representation of the configuration of the ground. The determination of the profile and cross-sections is usually accomplished by the ordinary engineer's level, but on side-hill work or where obstacles are frequent the cross-section rod gives better results. The longitudinal profile is plotted on profile paper which is especially printed for this purpose, and two different scales are used, one for the horizontal distances, which is usually 400 ft. to 1 in., and another for the vertical distances, which is usually 30 ft. to 1 in. The larger vertical scale gives a distorted profile, but one in which every irregularity of the surface is magnified, and this is its purpose. The grade-line of the proposed work is plotted on this profile at its proper elevation; all portions of the profile which come above this grade-line constitute cuts, and all portions which come below constitute fills. The points where the grade-line intersects the profile are called points at grade, and they are marked on the ground by stakes.

European engineers in plotting the profile adopt a somewhat different practice than that just described. Instead of setting the stakes marking the axis always 100 ft. apart, they set them wherever a change in direction occurs on the ground-surface. Thus, for instance, if the ground-surface is substantially unbroken the stakes may be set as much as 300 ft. apart, but

if the surface is very uneven the stakes may be set only a few feet apart. A heavy line is drawn to represent the datum plane, and parallel to it four other lines are drawn, one being marked with the elevations above datum of the ground-surface, another with the elevations above datum of the proposed work, and the third and fourth with the partial and the progressive datums of the various stakes or stations. As in American practice, horizontal distances and vertical elevations are drawn to different scales. Fig. 1 represents a profile drawn according to American practice, and Fig. 2 represents the same profile drawn according to European practice, in which all elevations, distances, grades, depths of cuts and fills, etc., are enumerated on the drawing. The longitudinal profile is generally supplemented by a plan which shows the developed grade-line of the proposed work.

The longitudinal profile alone does not completely show the configuration of the ground, and it is, therefore, supplemented by cross-sections which are in effect transverse profiles taken at chosen intervals and at right angles to the plane of the longitudinal profile. These cross-sections are determined by either an engineer's level or by a cross-section rod. They are plotted to a scale equal to the vertical scale of the profile, sometimes on the profile sheet, but more often on separate sheets. Each cross-section bears a number corresponding to the number on the profile which marks the point where the section was taken. Usually the cross-section is taken for a distance each side of the axis which is somewhat greater than that marking the outer limits of the projected work. A common practice is to cross-section a width three times as great as the width of the work. The purpose of this is to include the slopes of the cuts and fills and to permit if desired the axis to be shifted to one side or the other without the necessity of determining and plotting new cross-sections.

In plotting cross-sections the original ground-surface is denoted by a full black line and the surface of the proposed construction is denoted by a full line in red ink or a broken line in black ink. Fig. 3 is an example of a cross-section plotted in black ink. Here

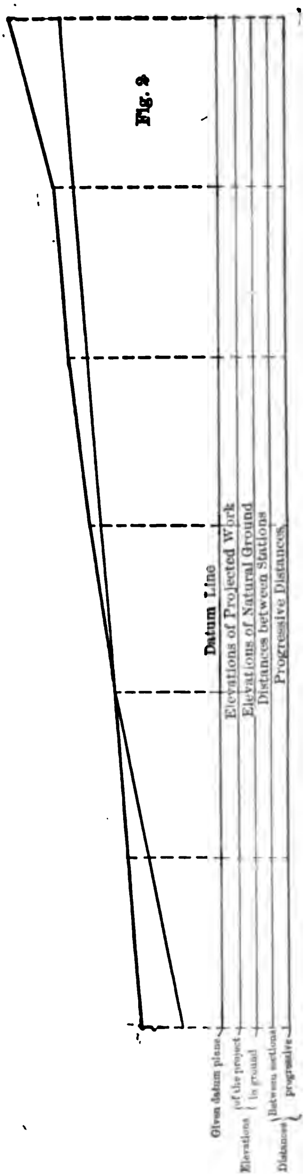


Fig. 2

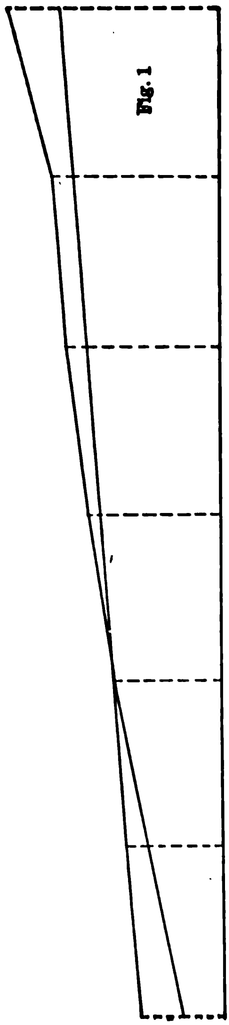


Fig. 1

Horizontal Scale $1/16'' - 50'$
Vertical $1/16'' - 20'$

the line *ABCD* represents the original ground-surface, and the line *AEFGHD* the surface of the proposed work. *A*, *K*, and *D* are points at grade. The triangle *AEK* shows a fill, and the

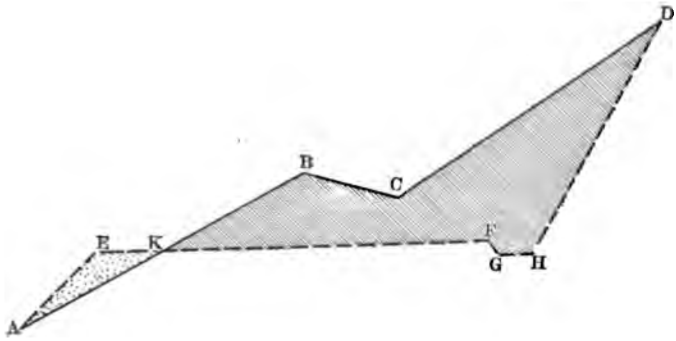


Fig. 3.

irregular figure *KBCDHGF* shows a cut. It is common practice in both the profile and the cross-sections either to enter the fills and cuts differently, or to use section-lining and stippling to distinguish them. The cross-sections are usually marked also with all dimensions, depths of cut and fill, slope of banks, etc. The total width of cross-section represents what French engineers

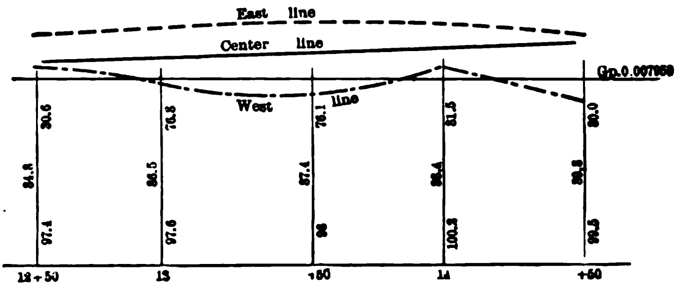


Fig. 4.

call the *emprise*, which is the strip of land occupied by the construction and whose boundaries it is very useful to know in determining the compensation to be paid the owners.

A modification of the method of profile and cross-sections, which is used in the Public Works departments of the city of New York, is illustrated by Fig. 4. The stations are taken 100 ft.

apart, and at each station the elevations of both side lines and the axis of the ground-surface are determined. These elevations give the engineer three profile lines, one at each boundary and one at the center line of the work, which are plotted as shown by the illustration, and with a different-colored ink or a different symbol for each line. The station-lines extended below the datum line serves as a basis for a plot of the cross-section at each station. The scale used is usually 100 ft. to 1 in. horizontal and 20 ft. to 1 in. vertical, but this scale is varied with the size of the work.

The method of longitudinal profile and cross-sections, while particularly adapted for representing long and narrow earthworks, can also be used for representing earthworks of more nearly equal lateral dimensions, such as reservoirs and railway yards. In such cases a series of cross-sections are taken perpendicular to a chosen base-line and equal distances apart.

CHAPTER II.

METHODS OF CALCULATING QUANTITIES AND COST OF EARTHWORK.

IN planning earthwork, as in planning any other engineering work, it is one of the first duties of the engineer to calculate its cost. The cost is given by multiplying the total volume of the work by a figure representing the estimated cost per unit of volume. The first thing to be determined in calculating the cost of earthwork is, then, the volume, and in this chapter we shall outline the various methods of performing this task which are practiced by engineers.

As already explained, earthwork is made up of cuts and fills; the total volume of any earthwork is, then, the sum of its cuts and fills. This sum is determined differently for works which occupy a long narrow area and for works which occupy areas of approximately equal lateral dimensions. We shall consider separately the methods adapted for each form of work.

WORKS LONG AND NARROW IN AREA.

When the work to be done occupies a very long and comparatively narrow strip of land it is usually represented by a longitudinal profile and numerous cross-sections, as already explained. The total amount of cut and fill is given by the sum of the cuts and fills between the consecutive cross-sections. There are several methods of determining the volume of cut and fill between two consecutive cross-sections. Some of these methods involve long calculations and give absolute results, and others require only short, simple calculations, and give only approximate results.

Correct Method.—Accurately speaking, there is no absolutely correct method for calculating earthwork. All calculations assume the solid to be figured to be bounded by planes, while the actual bounding surfaces are irregular and undulating. Assuming, however, that the solid is bounded by planes parallel to the vertical plane passing through the axis of construction, then the volume of that solid is easily obtained. If a and b are the areas of the two consecutive cross-sections, and d is their horizontal distance apart, then the volume of the solid between these cross-sections is represented by

$$V=\frac{a+b}{2}d.$$

It is, however, very seldom that the solid is bounded by planes parallel to the axis.

Let $ABCD$ and $EFGH$ (Fig. 5) be two consecutive cross-sections, of which the first is the smaller. From A and B draw planes parallel to the axis of the road; the larger cross-section will thus be divided into three parts—two triangles FJI and LKH, and the irregular polygon $IJFGLK$. The solid will likewise be divided into three other solids which are a large prismoid included between the planes parallel to the axis of the road, and two triangular pyramids with their vertices at A and B respectively.

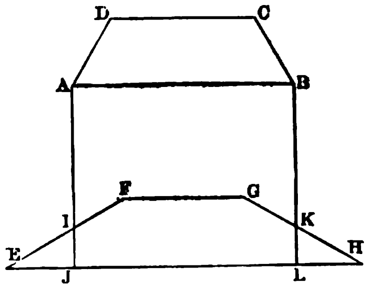


FIG. 5.

Let A = the area of the cross-section $ABCD$;
B = " " " " " $EFGH$;
α = " " " " triangle EIJ;
β = " " " " " KLH.

The volume of the solid will be,

$$V=\frac{A+B+\alpha+\beta}{2}d+\frac{\alpha+\beta}{3}d,$$

or

$$V=\frac{A+B}{2}d-\frac{\alpha+\beta}{6}d,$$

or

$$V=\frac{A+B-\frac{\alpha+\beta}{3}}{2}d.$$

The volume can also be obtained by graphics, as shown by Fig. 5*a*. On a horizontal line draw to any convenient scale a segment equal to d. At each extremity of this segment erect indefinite perpendiculars and lay off on them segments equal to A and to $B-\frac{\alpha+\beta}{3}$ respectively. These segments will contain as many lineal units as there are units of surface in the two areas. Close the figure by uniting C and D, and the trapezoid $ABCD$ will contain as many units of surface as there are units of volume included between the two cross-sections A and B.

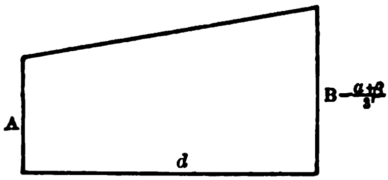


FIG. 5*a*.

Prismoidal Formula.—Mr. John D. Henck, C.E., in his *Field Book for Railroad Engineers,* says that any prismoid can be divided into prisms, wedges, and pyramids of equal altitude, and its volume can be easily obtained from the sum of the volumes of the various solids into which it has been divided. Let b be the base of any prism and let a be its altitude; its volume will then be given by

$$v=a\times b.$$

If b represent the base of a regular wedge, or half a parallelopipedon, and a represent its altitude, its volume will be given by

$$v=\tfrac{1}{2}a\times b.$$

If b represent the base of any pyramid with the altitude a, its volume will be

$$v=\tfrac{1}{3}a\times b.$$

The combined volumes of these three bodies admit of a common expression which may be found.

Let m represent the middle area of either of these solids, that is, the area of a section parallel to the base and midway between the base and top.

For the prism $m = b$.
For the wedge $m = \frac{1}{2}b$.
For the pyramid $m = \frac{1}{4}b$.

The upper base of the prism is equal to b and the upper bases of the wedge and pyramid are each zero. Then the expressions ab, $\frac{1}{2}ab$, and $\frac{1}{3}ab$, representing the volumes of the prism, wedge, and pyramid, may be thus transformed:

Solidity of prism $ab = \frac{a}{6} \times 6b = \frac{a}{6}(b+b+4b) = \frac{a}{6}(b+b+4m)$.

" " wedge $\frac{1}{2}ab = \frac{a}{6} \times 3b = \frac{a}{6}(0+b+4b) = \frac{a}{6}(0+b+4m)$.

" " pyramid $\frac{1}{3}ab = \frac{a}{6} \times 2b = \frac{a}{6}(0+b+\ b) = \frac{a}{6}(0+b+4m)$.

Hence the solidity of either of these bodies is found by adding together the area of the upper base, the area of the lower base, and four times the middle area, and multiplying the sum by one-sixth of the altitude. Irregular wedges, as those not half-parallelopipedons, may be measured by the same rule, since they are the sum or difference of a regular wedge and a pyramid of common altitude; and as the rule applies to both these bodies, it applies to their sum or difference.

Now, a prismoid, being made up of prisms, wedges, and pyramids of common altitude with itself, will have for its solidity the sum of the solidities of the combined solids. But the sum of the areas of the upper and lower bases of the combined solids is equal to $B+B'$, the sum of the areas of the parallel faces of the prismoid; and the sum of the middle areas of the combined solids is equal to M, the middle area of the prismoid. Therefore

$$S = \frac{a}{6}(B+B\ +4M),$$

which is the prismoidal formula commonly employed in the calculation of earthwork.

This formula can also be graphically represented, since it can be written

$$S=\frac{\frac{a}{3}(B+B_1)+4M}{2}.$$

Draw an indefinite horizontal line and lay off on a convenient scale a segment equal one-third the distance between the two cross-sections. At its extremities erect perpendiculars, and lay off on one the sum $B+B_1$ and on the other the sum $4M$. Close the figure by uniting C and D, and the figure $ABCD$ will contain as many units of surface as there are units of volume in the prismoid included between the two cross-sections A and B. To calculate earthwork by either the correct method or by the prismoidal formula, although not abstruse, is a long and tedious operation, so that it is common in actual work to adopt more expeditious methods.

Mean End Areas.—The simplest method of calculating earthwork is by averaging the areas of the two end sections and multiplying this sum by the distances between the cross-sections. If A and B are the areas of the two cross-sections and d is their distance apart, then the volume is given by

$$V=\frac{A+B}{2}d.$$

The volume of the prismoid thus calculated is greater than the volume obtained by the correct method, the difference being $\frac{\alpha+\beta}{6}$, or half the volume of the two pyramids separated from the prismoid by means of two vertical planes passing through the exterior ends of the smaller cross-section and parallel to the axis of the prismoid. The error will decrease the nearer the vertical bounding planes are to being parallel with the axial plane, and it will increase the more the bounding planes diverge from a parallel to the axial plane.

The calculation of the volume of earthwork, by averaging the end areas of the two cross-sections, is performed in two differ-

ent ways, either by measuring directly the quantities of cuts and fills included within the solid, or indirectly by taking the average of the quantities of cuts and fills in the two end areas and multiplying it by their distance apart.

Direct Method.—The direct method is more correct, although it is more complicate, and all the different cases which may be encountered will be considered.

1st Case. Both Cross-sections in Cut or Both in Fill.—This case has already been considered, and the volume is given by

$$V=\frac{A+B}{2}d.$$

This manner of measuring the volume can be compared with the area of a trapezium, *ABCD,* in which the parallel sides and the altitude are respectively proportional to the areas of the two cross-sections and their distance (Fig. 6). The trapezium will contain

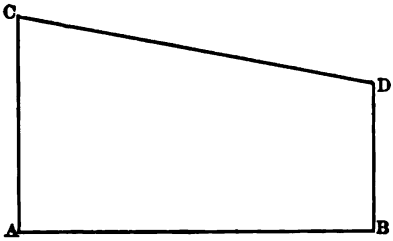


FIG. 6.

as many units of surface as there are units of volume in the solid.

2d Case. One section, A, in Cut and Cross-section, B, in Fill.—The volume of the cut is given by

$$C=\frac{A^2}{A+B}\frac{d}{2},$$

and that of the fill by

$$F=\frac{B^2}{A+B}\frac{d}{2}.$$

These volumes are clearly indicated by graphics (Fig. 7). On the horizontal line AB take a segment equal d; at its extremities erect perpendiculars in opposite directions. On one lay off a

segment equal to A, representing the cut; and make the other perpendicular equal to the fill B; unite C with D. The point O will be the point at grade. The units of surface in the triangle OAC will represent the units of volume of the cut, while those of

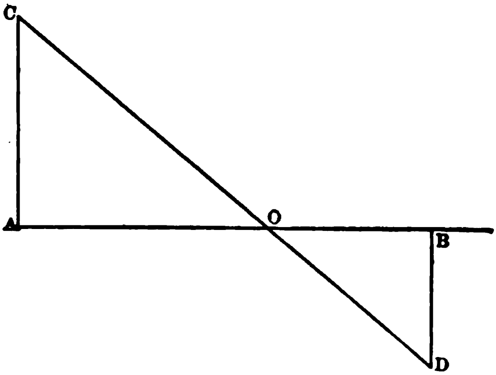


FIG. 7.

the triangle OBD will represent the volume of fill. The quantities of the cuts will be given by $\frac{A}{2}AO$, and those of the fills by $\frac{B}{2}BO$.

From the similar triangles AOC and BOD we have

$$A:B=AO:OB;$$

but

$$OB=AB-OA,$$

therefore

$$A:B=AO:AB-OA$$
$$B\times AO=A\times AB-A\times OA$$
$$B\times AO+A\times OA=A\times AB$$
$$AO(A+B)=A\times AB$$
$$AO=\frac{A\times AB}{A+B}.$$

AB being equal to d and the quantity of cut being given by $\frac{A}{2}AO$, then

$$\frac{A}{2}\times\frac{Ad}{A+B}=\frac{A^2}{A+B}\frac{d}{2}.$$

In a similar way it is found that the fill B is equal to $\frac{B^2}{A+B}\frac{d}{2}$.

3d Case. One Cross-section in Cut or Fill, and the other Cross-section Part in Cut and Part in Fill (Fig. 8).—The second section

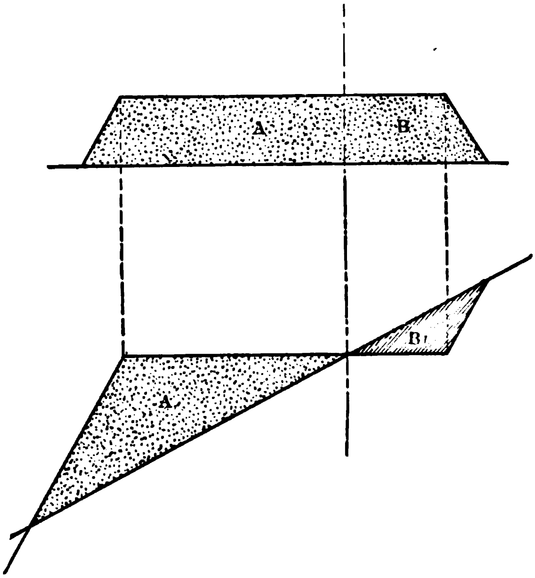


FIG. 8.

being part in cut and part in fill, the line of the project will intersect the ground-surface at the point O, thus dividing this cross-section into the parts B and B_1, the former in fill and the latter in cut. Imagine a vertical plane passing through O and parallel to the axis of the construction; this will divide the first cross-section into two parts, A and A', both in fill. The volume of the fill at the left of this vertical plane is given, according to the 1st case, by $\frac{A+A_1}{2}d$, and the volumes at the right-hand side of the same vertical plane are given, according to the 2d case, by

$$\text{cut} = \frac{B_1^2}{B+B_1}\frac{d}{2} \quad \text{and} \quad \text{fill} = \frac{B^2}{B+B'}\frac{d}{2}.$$

So that the total volume of the solid will be

$$\text{Fill} = \frac{A+A'}{2}d + \frac{B^2}{B+B_1}\frac{d}{2},$$

$$\text{Cut} = \frac{B_1^2}{B+B_1}\frac{d}{2}.$$

4th Case. Both Cross-sections are Part in Cut and Part in Fill, and the Points at Grade Correspond with the Axis of the Construction (Fig. 9).—The volumes of the cuts and fills are cal-

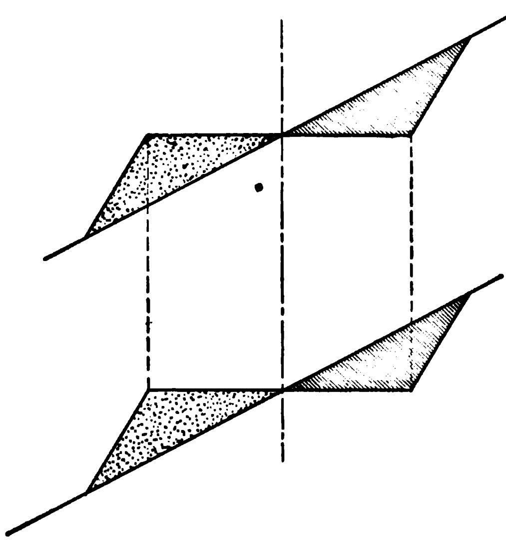


FIG. 9.

culated as in the first case. If a vertical plane is supposed to pass through the axis of the construction, we have at the left hand two cross-sections, A and B, both in fill, and the volume will be given by $\frac{A+B}{2}d$; at the right-hand side of the vertical plane there are two sections, A_1 and B_1, both in cut, and the volume will be given by $\frac{A_1+B_1}{2}d$. Between these two cross-sections we shall have

$$\text{Cut} = \frac{A+B}{2}d \quad \text{and} \quad \text{Fill} = \frac{A_1+B_1}{2}d.$$

5th Case. Both Cross-sections are Part in Cut and Part in Fill, but the Points at Grade are not Along the Same Vertical Plane.—From the points at grade O and O_1, Fig. 10, draw two

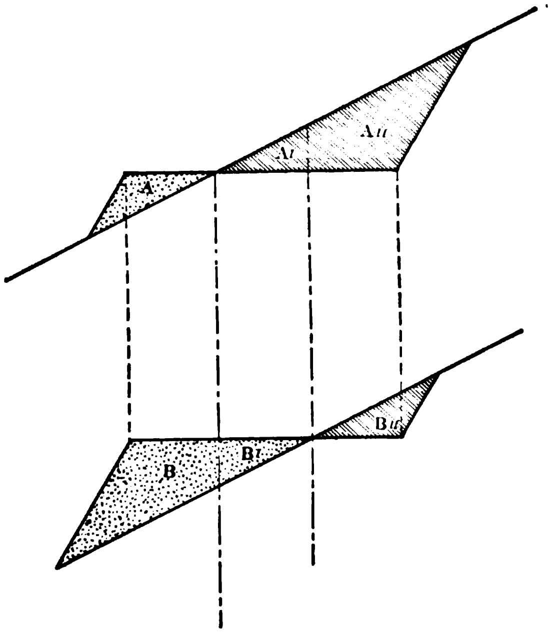


FIG. 10.

vertical planes parallel to the axis of the construction. These planes will divide the two cross-sections into three parts, A, A_I, A_{II} and B, B_I, B_{II}, respectively. The volume of the solid contained between these two cross-sections is the sum of the cuts and fills of these new solids into which the former solid was divided; and they are limited by A and B, A_I and B_I, A_{II} and B_{II}. A and B being both in fill, the volume is given by $\frac{A+B}{2}d$. The sections A_I being in cut and B_I in fill, the volume of the cut is given by $\frac{A_I^2+B}{A_I^2}\frac{d}{2}$, and that of the fill by $\frac{B_I^2}{A_I+B_I}\frac{d}{2}$. The sections A_{II} and B_{II} being both in cut, the volume is given by $\frac{A_{II}+B_{II}}{2}d$. The

total volume of the solid included between the two cross-sections will be

$$\text{Cut} = \frac{A_I^2}{A_I + B_I}\frac{d}{2} + \frac{A_{II} + B_{II}}{2}d;$$

$$\text{Fill} = \frac{A+B}{2}d + \frac{B_I^2}{A_I + B_I}\frac{d}{2}.$$

Indirect Method.— It is easier, although less accurate, to calculate the volumes of the earthwork by the mean end-area method in an indirect way, and this is done by the simple construction of tables in which are recorded all the data and calculations. The following table, taken from Lenti, gives the method employed by the Italian government engineers for calculating the volumes of earthwork. This is obtained by marking separately the area of the cuts and fills on each cross-section, and then taking the average of the areas of cuts and fills between two consecutive cross-sections. These averaged areas are multiplied by the distance of the cross-section apart, and thus the volumes of the cuts and fills are obtained.

The table for the calculation of the earthwork contains only eight columns, but a few others are added in order to keep record and for calculating also the amount of the different kinds of soil encountered in the excavation. In the first column are recorded the various cross-sections progressively; in columns 2 and 3 are marked the area of the cut or fill in the corresponding cross-section; in columns 4 and 5 are marked the averaged areas of the cuts and fills between the two consecutive cross-sections; in column 6 are recorded the distances between the two consecutive cross-sections, and in columns 7 and 8 are given the volumes of the cuts and fills, or the products of columns 4 and 6, and 5 and 6, respectively. The sum of columns 7 and 8 will give the total amount of cuts and fills required for the construction of the road, as indicated by the longitudinal profile and cross-section. In columns 9, 10, and 11 are recorded the amount of earth of the cuts, classified according to their resistance. If they are of vegetable ground or loose soil, in column 9; resistant and compact soils, as

clay and gravel, in column 10; and in column 11 the rock. Another column is usually added in which are recorded all the observations relating to the work. It is, however, to be remembered that in the first column, as, for instance, between sections 3 and 4, 5 and 6, and 7 and 8, there are supplementary cross-sections marked P.G.; this means points at grade, and they should always be recorded. These points at grade are given by writing in columns 2 and 3 the same values of F. or C. that are marked in columns 2 and 3 in the consecutive cross-section or the successive one.

TABLE I.

Progressive Number of the Cross-sections.	Surface of Sections.		Averaged Surfaces.		Distance between the Successive Cross-sections.	Volumes.		Nature of the Soil.			Observations.
	Fillings.	Cuts.	Fillings.	Cuts.		Fillings.	Cuts.	Loose Soil.	Persistent Soil.	Rock.	
1	0.00	0.00									
			0.56	1.81	30	16.80	54.30	34.30	20		
2	1.12	3.62									
			0.81	4.54	18.80	15.22	85.35	55.35	30		
3	0.50	5.45									
P.G.	0.50	5.45	0.25	1	12.02	3.00					
				8.87	29.60	3.00	262.55	162.55	100		
4	0.00	12.28									
				14.25	14.30		203.51	103.51	100		
5	0.00	16.22									
			0.25	14.25	4.35	1.09					
P.G.	0.49	16.22									
				13.41	15.00		201.15	101.15	100		
6	0.49	10.61									
			2.40	8.69	15.00	36.00	130.35	80.35	50		
7	4.31	6.76									
			2.40	6.93	14.80	102.56					
P.G.	0.00	6.76									
			20	3.38	12.07	102.56	40.80	21.80	1900		
8	9.54	0.00									
			15.78		13.70	216.19					
9	22.01	0.00	15.78								

French engineers use another method for calculating the total amount of cuts and fills in earthwork excavations. They do not take the average of the two consecutive cross-sections as

the Italian engineers do, but they calculate directly the solids contained between the two cross-sections as having a constant base and equal to the second of the cross-sections considered. Besides, on each cross-section they calculate separately the portions at the right and left of the axis of the construction and make up a table of ten columns, with an additional one for the observations regarding the work. The sums of columns 6 and 10 give the total amount of the cuts and fills, respectively, required for the work. The following table, illustrating this method, is taken from Daries.

TABLE II.

Number of Cross-section. 1	Distance. 2	Cuts. Right. 3	Cuts. Left. 4	Cuts. Total. 5	Cuts. Volumes. 6	Fillings. Right. 7	Fillings. Left. 8	Fillings. Total. 9	Fillings. Volumes. 10	Observations. 11
1	21.47	......	......	......	......	15.50	9.97	25.47	547	
P.G.	30.50									
2	42.53	2.03	8.68	10.71	455					
3	56.50	12.20	22.25	34.35	1946					
4	50	......	1.87	1.87	94	12.07	2.24	14.31	716	
5	39.50	20.12	20.49	40.61	1604					
6	36.62	12.55	10.90	23.45	859					
P.G	43.50									
7	53.88	......	......	......	......	8.53	10.32	18.85	1016	
8	45.00	......	......	......	......	13.19	29.91	43.10	1940	
9	28.00	0.54	......	0.54	15	0.37	5.08	5.45	153	
10	17.50	4.16	......	4.16	73	0.15	5.93	6.13	107	
	465				5046				4479	

All the numbers are in meters, and consequently for a distance of 465 meters will be 5046 cubic meters of cuts and 4479 cubic meters of fillings.

Profile of Masses.—From the end-area method used in the calculation of earthwork can be easily constructed the profile of the masses, which is the graphical representation of all the cuts and fills required for the work. Besides, it will give a correct idea in what direction, either longitudinally or transversally to the axis of the construction, the earth should be moved from their present position in order to reduce the ground in the manner indicated in the project.

Considering, for instance, the cross-sections whose dimensions and calculation of the earthwork are given in Table I, the profile of the masses is drawn in the following manner. A horizontal line, XY, represents the longitudinal axis of the construction, and along this are marked points representing the distances of the various cross-sections from the origin. The origin in our case will be at the cross-section 1, and it must be taken a distance along XY equal to 30, so as to have the point of the cross-section No. 2, and then another segment equal 18.80 will indicate the point of the section 3, and 12.02 indicate the point at grade, and again the distance of 29.60 from this will give the location of the cross-section 4, and so on. In a word, along the horizontal line XY are laid off segments representing in scale the distances apart of the various cross-sections. At these points are erected perpendicular lines, and on these are laid off segments representing the area of the various cross-sections. The segments representing the cuts are laid off above the horizontal line, and those representing the fills are laid off below. The scale used to represent the areas is usually different and much larger than the one employed for the distances. Station 1, in which there are neither cuts nor fills, as indicated in the table, is the origin. Then along the perpendicular erected at the station 2 above is laid off a segment equal to 3.62, representing the cut, and below another equal to 1.12, representing the fill. On section 3 above there is a cut of 5.46, and below a fill equal to 0.50; then at the point P.G., which is distant 12.02 from station 3, there are no more fills and all the sections are in cuts. Thus there is found on section 4 a cut of 12.28, and 16.22 at the station 5. At a point 1.35 from station 5 there is the point at grade P.G., because the fills begin again, and it is found to be 0.49 at station 6, while the cut is 10.61. At station 7 the cut is 6.76 and the fill 4.31, and the cuts come to 0 at the P.G. 14.8 from station 7. Then stations 8 and 9 are all in fills, and segments equal to 9.54 and 22.01, respectively, are laid off. Connecting all the points above the horizontal line XY, an irregular figure is obtained which will contain as many units of surface as there are units of volume in the cuts

to be made; while the irregular figure below the line XY will have as many units of surface as there are units of volume in the fills to be made, so as to reduce the present ground-surface as required by the project.

This diagram, given in Fig. 11, gives a clear idea of the direc-

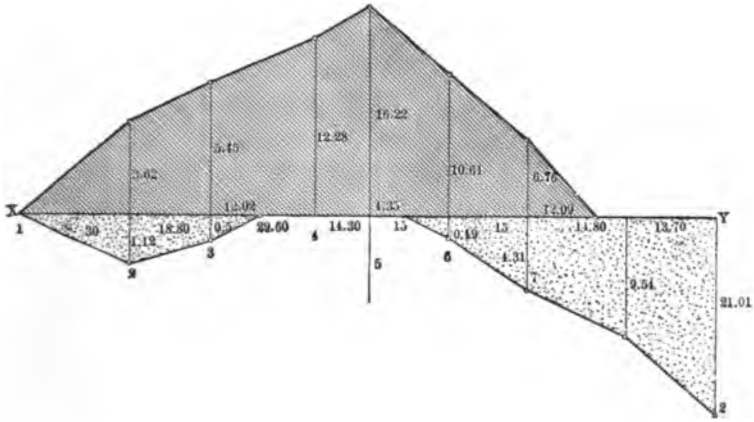


Fig. 11.

tion of the movements of the masses of earth, the portions that are compensated on the same cross-section, and those which have to be transferred along the longitudinal axis of the road. It is the real graphical representation of the cuts and fills which is required for the construction of the work between the two limiting cross-sections 1 and 9.

Rough Calculation Deduced from the Longitudinal Profile.— In some particular cases a rough calculation of the earthwork can be obtained in a very simple way by being directly deduced from the longitudinal profile of the axis of the construction. The tedious work of calculating all the volume of the prisms included within the various cross-sections is in this manner dispensed with. But this method is possible only when the surface of the project is parallel to the ground-surface. It consists in calculating the volumes of the cuts and fills for the various portions of the road. For each portion which is either in cut or in fill calculate a standard cross-section whose dimen-

sions are the average dimensions of the various cross-sections of this portion of the road. Such an average area multiplied by the total length of the considered portion will give the volume of cut or fill for that portion of the road. Repeating the same operation for each of the various portions into which the road has been divided, the total volume of the cuts and the fills required for the work can be easily deduced. It is obvious that such a manner of calculating the volumes of the cuts and fills would be entirely wrong in cases where the cross-sections were part in cut and part in fill, and in cases in which the surface of the road-bed is inclined to the ground-surface.

Calculation of Earthwork Extending Over Large Surfaces.— So far we have reviewed only the various methods of calculating earthworks in works greatly extending in length while the width of the construction was very narrow. But there are cases in which the work extends in width as well as in length, and this chiefly happens in the construction of storage-reservoirs for the supply of water to the cities, and in preparing lands for irrigation, for industrial and other purposes. The calculation of the earthwork in these cases can be performed in three different ways: by longitudinal profile and cross-sections; by fixing the grade at which the land should be reduced so that all the cuts may be employed to fill in all the cavities; and finally to calculate directly the quantity of earth to be removed so as to reduce the land to the required grade.

(1) The method of calculating the volume of earthwork by means of longitudinal profile and cross-sections is identical with the one already described. At first the topographical survey of the land is made by ranging on the ground a base-line as near as possible to the axis of the figure. This is used in the same way as the axis of the construction in the longitudinal profile. Then along this every 100, 50, and even smaller number of feet apart, depending upon the degree of accuracy required in the work, are erected perpendicular lines and the various altitudes of the points 100, 50, 25, or 10 apart right and left from the axis are recorded. In this manner are made the various cross-sections

and the line of the project is drawn. The parts above or below this line represent the cuts and the fills required to reduce the actual ground-surface to the required grades, and are marked for each section. The average areas of the cuts or fills of the consecutive cross-sections multiplied by their distance will give the volumes of the cuts and fills between them. By calculating the cuts and fills required between all the various cross-sections is obtained the calculation of the total amount of earthwork required for the work.

This method is very simple, and it is the one most commonly employed on practical works; and it may without great error be said that it is the only one employed in this country. The calculation of the earthwork for the Jerome Park Reservoir which is now under construction in the Bronx Borough in connection with the water-supply for the city of New York is done exclusively by means of longitudinal profile and cross-section notwithstanding it occupies a stretch of land extending for nearly 1½ miles in length and ¾ of a mile in width.

(2) But it may happen that it is desired to know the elevation of a plane at which the land should be reduced in order that all the earth excavated from the cuts may be used to compensate the fills. For convenience suppose a polygonal area *ABCDE*, Fig. 12, for which it is desired to find the altitude of a plane at which all the cuts and fills will be compensated. There is an interior point *O* which is the highest of all. Connecting this point *O* with the various vertices of the polygon *ABCDE*, the figure will be divided into a series of triangles *AOB*, *BOC*, *COD*, *DOE*, *EOA*. The altitude of the various points being given as indicated on the figure, the volume of the earth included between a given datum plane and the ground-surface will be given by the sum of all the triangular prisms having for bases the various triangles, the corresponding edges of the prisms being the altitude from the given datum plane. Thus, for instance, the edges of the prism having for a base the triangle *AOB* will be 3, 15, and 5 respectively, while 5, 15, and 7 will be those of the prism having for a base the triangle *BOC*. The volume of all these various

prisms divided by the total area of the polgyon *ABCDE* will give the altitude of the ordinate *H* of the horizontal plane of equal cuts and fills.

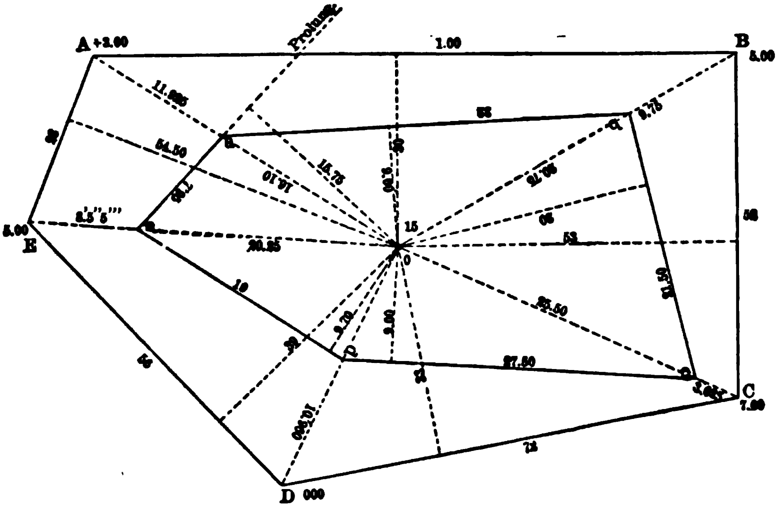


FIG. 12.

	Sq. Ft.	Cu. Ft.
Area *AOB*	$=\frac{100\times 30}{2}=1500$	Volume, $1500\times\frac{23}{3}=11{,}500$
Area *BOC*	$=\frac{52\times 53}{2}=1378$	Volume, $1378\times\frac{27}{3}=12{,}402$
Area *COD*	$=\frac{72\times 33}{2}=1188$	Volume, $1188\times\frac{22}{3}=\ 8{,}712$
Area *DOE*	$=\frac{56\times 39}{2}=1092$	Volume, $1087\times\frac{20}{3}=\ 7{,}246.666$
Area *EOA*	$=\frac{28\times 54.5}{2}=\ 763$	Volume, $763\times\frac{23}{3}=\ 5{,}849.666$
Area *ABCDE* =	5921	Volume $=\ 45{,}710.332$

The altitude of the plane of equal cuts and fills will be given by the volume divided by the area, or

$$H=\frac{V}{A}=\frac{45{,}710.332}{5921}=7.72.$$

The horizontal plane drawn at an altitude of 7.67 ft. from the lowest point D will intersect the sides of the various triangles into which the polygon $ABCDE$ was divided, at the points $a\ b\ c\ d\ e$. Uniting now these points with O, it will follow that the area of this new polygon will be equal to the sum of the areas of the various triangles into which this new polygon was divided.

Thus we shall have:

$$\begin{aligned}
\text{Area } boa &= 144.00\\
\text{Area } bOc &= 1215.00\\
\text{Area } cOd &= 123.75\\
\text{Area } bOe &= 92.15\\
\text{Area } eOa &= 610.3125\\
\hline
\text{Area of the polygon } abcde &= 2185.2125
\end{aligned}$$

The altitude of O above the plane of the polygon $abcde$ is $15-H$ or $15-7.67=7.33$, and the volume of the cuts will be given by the pyramid having the polygon $abcde$ as a base and O as vertex, and consequently it will be

$$2185.2125 \times \frac{7.33}{3} = 5336.5358.$$

(3) In order to calculate directly the volume of the cuts required to reduce a tract of ground to the required grade, consider the former example and suppose we are to reduce the ground to the ordinate H above the given datum plane passing through the point D. V being the actual volume of the earth above the datum plane, AH will be the volume of the earth which will remain, and the excess to be hauled away will be $V-AH$, while the volume of the earth to be used in filling will be $V_1-(V+AH)$.

For sake of simplicity suppose we have an area of rectangular shape $ABCD$, in which the various altitudes of the prominent points are marked in Fig. 13, their distances also being given. Suppose now that it is required to reduce this ground to a horizontal plane at grade with the point E, whose ordinate is 12 ft.

The area of the surface is 3500 sq. ft., and the volume above the given datum plane after the work is done will be

$$12A = 42{,}000 \text{ cu. ft.},$$

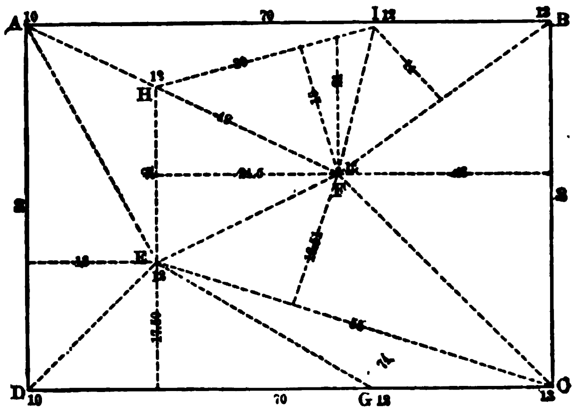


Fig. 13.

while the actual volume above the datum plane is given by the sum of the various volumes, as follows:

$$\frac{70\times 21}{2}\times\frac{10+13+15}{3}=735.00\times 12.66= 9{,}305.10$$
$$\frac{50\times 28}{2}\times\frac{13+13+15}{3}=700.00\times 13.66= 9{,}562.00$$
$$\frac{55\times 18.51}{2}\times\frac{12+13+15}{3}=509.02\times 13.33= 6{,}785.23$$
$$\frac{70\times 17.5}{2}\times\frac{10+12+13}{3}=612.50\times 11.66= 7{,}141.75$$
$$\frac{50\times 18}{2}\times\frac{10+10+12}{3}=450.00\times 10.66= 4{,}797.00$$
$$\frac{47\times 21}{2}\times\frac{10+12+15}{3}=493.50\times 12.33= \underline{6{,}084.85}$$
$$\text{or}\quad V=43{,}675.93$$

We find, therefore, that the volume to be hauled away is

$$V-12A=43{,}675.93-42{,}000=1675.93 \text{ cu. ft.}$$

By proportion the vertices of the broken line *GEHI* intersecting the horizontal plane of reduction with the surface-ground are easily fixed. Then we determine the area A_s of this cut *HIBCGE*, which is

$$A_s = FIH + BFL + BCF + CEF + CEG + EFH =$$
$$= \frac{30\times 19}{2} + \frac{35\times 14}{2} + \frac{28\times 50}{2} + \frac{55\times 18.51}{2} + \frac{55\times 9.4}{2} + \frac{24\times 24.5}{2}$$
$$= 285 + 245 + 700 + 509.02 + 258.5 + 294 = 2291.52 \text{ sq. ft.,}$$

and the volume of the cut

$$V_s = 294.5 + 245\tfrac{4}{3} + 700\tfrac{5}{3} + 509.02\tfrac{4}{3} + 206.25\tfrac{1}{3} + 300.12$$
$$= 294.2 + 326.66 + 1166.66 + 678.69 + 67.83 + 294.00$$
$$= 2828.04 \text{ cu. ft.,}$$

and the volume of the earth to be used in filling is

$$V_s - V + 12A = 2818.84 - 1675.93 = 1142.91 \text{ cu. ft.}$$

CHAPTER III.

CUTS AND FILLS; BORROW-PITS AND SPOIL-BANKS.

IN many text-books it is stated in the most absolute manner that on any longitudinal profile of earthwork the grade-line should be established in such a position that the cuts will balance the fills. As a simple and practical means of insuring this balance it is suggested that a thread stretched in the hands be moved up and down the profile until the portions above the thread appear closely to equal in area the portions below the thread. This rule for locating the grade-line should be discountenanced by the engineer, and he should base the location of his grade-line on more scientific principles and independently of the cuts and fills. In many instances, as will be shown farther on, it will be found more convenient to build up the fills from borrow-pits and waste the material from the cuts in spoil-banks than to attempt to compensate one by the other.

As a rule earthwork comprises both cuts and fills. The earth excavated from the cuts may be utilized to form the fills, or, if not needed for this purpose, it may be wasted at some convenient place along the work, thus forming what are commonly called waste- or spoil-banks. Likewise the fills may be formed of the materials excavated from the cuts, or they may be built up of materials taken from places near and alongside but off the line of the work which are called borrow-pits. When the material taken from the cuts exactly forms the fills the work is said to be compensated, but when the material from the cuts is in excess of or falls below the amount required to make the fills, the work is said to be done by spoil-banks or borrow-pits. There are, therefore, two distinct methods of performing earthwork, viz.,

by compensation or by spoil-banks and borrow-pits. Sometimes, however, notwithstanding the fact that the volume of the cuts equals the volume of the fills, the distance between the cuts and the fills may be so great that the long haul will tend to increase greatly the unit cost of the work. In such cases it is found more economical to perform part of the work by compensation and part by spoil-banks and borrow-pits; this gives a third method which is called the mixed method.

It is of the utmost importance that the engineer should know which of the three methods described for performing earthwork is the most economical in any particular case. To give a complete answer to this problem we should have to pass in review all possible cases in a large variety of different forms of work, which is an almost impossible task. It is better, therefore, to give such general rules as have been accepted by engineers as the result of numerous observations, calculations, and estimates.

It is generally admitted that it is more convenient to compensate the cuts and fills in the following cases:

(1) When the quantity of material to be moved from cuts to fills is so large that, notwithstanding the large investment of capital required in the construction of roads and in the purchase of plant, the unit cost of the filling will be the smallest possible.

(2) When, on account of the character of the locality, the spoil-banks and borrow-pits cannot be located near the work and a long haul perpendicular to the line of the work is necessary.

(3) When the land through which the work passes is so valuable that it is necessary to keep the area disturbed by the work within the narrowest possible limits.

The method of spoil-banks and borrow-pits is considered to be the most convenient in the following cases:

(1) When the material taken from the cut is so loose or treacherous that the embankment formed of it would be neither stable nor safe.

(2) When the volume of cuts and fills is so small that the roads and plant required will increase the cost of transportation per unit of volume.

(3) When the value of the land occupied by the work is nil or very small.

(4) When on account of the short time allowed for the construction of the work it is necessary to prosecute it simultaneously at numerous points along the line.

(5) When material obstacles such as mountains or ravines prevent the transportation of the material taken from the cuts to the points where fills are necessary, until the proposed tunnels and bridges are built, which is usually the last part of the work.

(6) When the distance between the cuts and fills is so great that, notwithstanding the cost of purchasing the land for spoil-banks and borrow-pits, the double excavation and the double volume of transported material, the cost of the work will be less than if done by compensation.

It is impossible to state absolutely which of the two methods of work is to be preferred; the selection depends upon land and special circumstances such as the limits of time, the quantity of earth taken from the excavation, etc. In general the mixed method will be found cheaper where the length of the work is considerable, compensation being employed where the conditions are favorable and spoil-banks and borrow-pits where the conditions are unfavorable to compensation. To determine exactly the points at which one method ceases and the other begins to be advantageous, resort must be had to higher mathematics. In actual work, however, mathematical accuracy is not required, and the practice usually followed is to determine the points named by trial. Whatever means of determination is adopted it is always desirable that the engineer and constructor should know in advance the fills for which excavation from cuts is to be used and from what cuts it is to come, and also the fills for which material from borrow-pits is to be used and where these borrow-pits are located. This knowledge is necessary to secure a regular and uniform plan of work, and is even more essential for determining the mean length of haul. It is impossible to estimate the cost of earthwork without having previously calculated the mean distance of haul, for unless this distance is known

the cost of hauling, which is one of the most important cost items of the whole work, cannot be accurately determined.

Different methods are employed for determining the distribution of the volumes of earth along the profile of the work. Italian and French engineers usually calculate it algebraically, while German and some French engineers determine it by graphical methods. In the United States no attention is paid to the distribution of volumes along the line, either in public or in private works. As a consequence the mean distance of haul is not known, and earthwork is never calculated on scientific principles in the United States. The author being aware that even the United States Engineer Corps, which is in charge of all works executed by the Federal Government, did not consider this factor, requested the Chief of Engineers to explain the reason for this important omission, and received the evasive answer that he was sorry that he had no printed matter for distribution dealing with this subject.

The simplest manner of obtaining the distribution of masses and the mean distance of haul is that employed by Italian engineers, which is deduced in a very simple manner from the calculations of the earthwork. The information is given in the form of a table made up of ten columns as follows:

Sections.	Distances between Sections.	Volumes.		Excesses.		Employment of the Earth.	Partial Volumes of Cuts.	Distance of Haul.	Product of the Volume by the Distance.
		Cuts.	Fillings.	Cuts.	Fills.				
						90 hauled bet. sections 2–3	90	77	6,930
0–1	....	845	285	560	....	310 " " " 3–4	310	114	35,340
	49	....	....	....	....	160 " " " 4–5	160	177	28,320
1–2	....	327	187	140	....	140 " " " 4–5	140	128	17,920
2–3	28	119	209	....	90	90 taken from sections 0–1			
3–4	37	....	310	....	310	310 " " " 0–1			
	63	....	....	....	....	160 " " " 1–2			
4–5	....	....	540	....	540	140 " " " 1–2			
	19	....	....	....	....	240 " " " 5–6			
5–6	....	320	52	268	....	240 brought to sections 4–5	240	19	4,560
	51	....	....	....	....	28 " " " 6–7	28	51	1,428
6–7	....	70	98	....	28	28 taken from sections 5–6			
	247	1681	1681	968	968		968		94,498

Referring to this table it will be seen that in the first section there is an excess of 560 cu. m. of cut, and between sections 1–2 an

excess of 140 cu. m., while the fill exceeds the cut in the portion of the road between sections 2 and 5. The excess of cut has to be brought to the points where it is needed for fill, and consequently the 560 cu. m. will be distributed as follows: 90 cu. m. as near as possible and consequently between sections 2 and 3, at a distance of 49+28=77 m.; 310 m. between sections 3 and 4 at a distance of 49+28+37=114 m.; 160 cu. m. between sections 4 and 5 at a distance of 114+63=177 m. Having disposed of the 560 cu. m. excess of section 0–1, we have next to dispose of the excess of 140 cu. m. of section 1–2, and this is taken to section 4–5, as indicated by the table, which can be consulted also for information regarding the procedure for succeeding sections.

French engineers employ a table constructed on the same principle, but more complicated in form. It contains 19 columns and considers separately transportation by wheelbarrows and carts. The following example of this French tabulation is taken from Daries's *Cubature des Terrassements* (Table II). The figures in columns 1 to 5 are obtained from the calculation of the volumes of earth required for the work. Those in column 6 represent the volumes moved by means of shovels, and consequently in a direction transversely to the axis of the work. In columns 7 to 10, inclusive, are given the excesses of cut and fill which have to be distributed along the axis of the work. Column 11 shows the excess volume of cut to be used as fill, column 12 the excess volume of cut to be wasted, and column 13 the volume to be taken from borrow-pits. In column 14 are indicated the places to which the excess volume of the cuts is to be taken. Column 15 shows the lengths of haul; if this length is less than 90 m. the calculations are placed in columns 16 and 17, and if it is greater than 90 m. they are placed in columns 18 and 19. After the table is completed and the calculations made, if the work is correct, the following equations should result. Sn being the sum of the column marked n,

$$S_4 = S_6 + S_{11} + S_{12}$$
$$S_5 = S_6 + S_{11} + S_{15}$$
$$S_4 + S_{13} = S_5 + S_{12}$$
$$S_{11} + S_{12} + S_{13} = S_{16} + S_{18}.$$

1 Number of Cross-section.	2 Volume of Cuts on Each Section.	3	4 Definite Volumes of Cuts.	5 Volumes of Fillings on Each Section.	6 Volumes to be Employed in the Portion between Two Sections.	Excess of the Cut on Fillings. 7 On Each Cross-section.	Excess of the Cut on Fillings. 8 In the Adjacent Cross-sections.	Excess of the Fillings on the Cut. 9 On Each Cross-section.	Excess of the Fillings on the Cut. 10 In the Adjacent Cross-sections.	Volumes of the Excess of the Cuts. 11 To be Carried Along the Lines.	Volumes of the Excess of the Cuts. 12 To be Deposited for Some other Purpose.	13 Borrow-pits for the Fillings.	14 Indication of the Place where the Excess of the Cuts should be Deposited.	15 Distance of Hauling.	Wheelbarrow. 16 Volumes.	Wheelbarrow. 17 Products of the Volumes by the Distance.	Carts and Wagons. 18 Volumes.	Carts and Wagons. 19 Products of the Volumes by the Distance.
1				547				547										
2	455		455			455				455			On Section 1	61	455	27,755		
3	1946		1946			1946				92			" " 1	128			92	11,776
"											567		On a lateral spoil-bank	30	567	17,010		
"										34			On Section 10	337			34	11,458
"										138			" " 9	302			138	41,676
"										493			" " 8	281			493	138,533
4	94		94	716	94					622			" " 4	46	622	28,612		
5	1604		1604			1604				1447			" " 8	181			1447	261,907
"										157			" " 7	112			157	17,584
6	859		859			859				859			" " 7	87	859	74,733		
7				1016				1016										
8				1940				1940										
9	15		15	153	15			138										
10	73		93	107	73			34										
															2503	148,110	2361	482,934

Mean distance of hauling with wheelbarrow $\frac{148,110}{2503} = 59$ meters;

" " " " " cart and wagon $\frac{482,934}{2361} = 205$ meters.

The distribution of the earth along the profile may be calculated graphically by the curves of Bruckner and Lalanne.

Bruckner's Curve.—The figure known as Bruckner's curve is constructed as follows: Along a horizontal line indicating the longitudinal profile of the axis of construction are marked to scale the distances between the various cross-sections and through each point is drawn a perpendicular line. On these perpendiculars are laid off the algebraic sum of the cuts and fills, the cuts being considered as positives and the fills as negatives. When the result is positive the amount is laid off above the horizontal line, and where it is negative the amount is laid off below the horizontal line. By connecting the extremities of the succeeding ordinates by straight lines or parabolic curves the resulting figure forms what is called Bruckner's curve (Fig. 14). This curve is constructed upon the following assumptions.

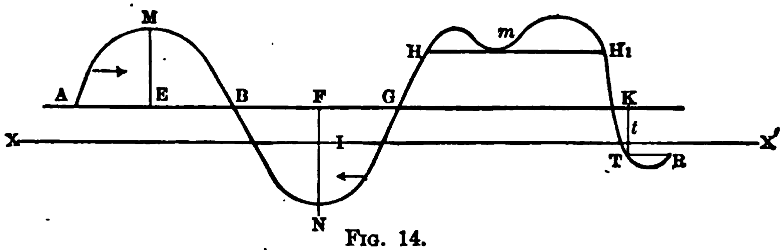


FIG. 14.

(1) That each mass of cuts and fills is concentrated on its corresponding point of the longitudinal profile.

(2) That on each cross-section only the excesses of the cuts over the fills, or vice versa, are recorded, and consequently the volume of earth transferred from cut to fill by shovel is not considered.

Bruckner's curve possesses a number of important properties which may be summarized as follows:

(1) The maximum and minimum of the curve correspond to the points at grade where the cut ends and the fill begins, or vice versa; thus the points M and N (Fig. 14) are points at grade.

(2) The nature of the work is the same in the space between a maximum and a succeeding minimum, and is always cut; it is

also the same between a minimum and a succeeding maximum and is always fill. Thus in Fig. 13 the work between A and M is cut, E and F being points at grade.

(3) The base-line detaches from the curve segments whose bases represent sections of line in which the cuts and fills are compensated. Thus the cuts equal the fills for the section of line AB, and the common volume is represented by the line EM.

(4) Considering any section AB in which the fills MB are made with materials taken from the cuts AM, the surface AMB represents the sum of the moments of the corresponding haul (products of the volumes by the distance).

Property No. 3 of the curve indicates a method of distributing along the axis of the construction the materials obtained from the cuts. But since this solution is possible for every line parallel to the ground-line and each one will give a new distribution of the earth, among the infinite solutions must be selected the one which requires the minimum of transportation. In giving the line of distribution two conditions must be observed:

(1) That the sum of the surfaces of the segment separated by this line on the curve be the minimum.

(2) That the volume of materials taken from borrow-pits or deposited on the spoil-banks must not be increased.

Several cases may happen. The curve of Bruckner ends at the ground-line, or else it ends either above or below the ground-line. If the extreme of the curve ends at the ground-line this is the line of distribution of the masses. But if the curve of Bruckner ends above or below it, from the free end of the curve is drawn a horizontal line. Afterward are calculated the respective sums of the chords intercepted by the ground-line in the segments that increase and decrease in a plan toward the free end of the polygon; if the first sum is greater than the second then the ground-line is the line representing the distribution of the volumes; otherwise the line is raised up or lowered until the sums of the opposite segments are equal. The position of the lines satisfying such a condition is the line of the distribution of the volumes; but when it is not satisfied before the free end of

the curves is reached, then from this extreme is drawn a horizontal line, and this will be the line of the distribution of the masses.

Lalanne's Curve.—This is the only graphical method employed by French engineers for calculating the distribution of the earths along the longitudinal profile of the construction as well as the mean distance of hauling. It is older than the Bruckner curve and it can be considered as a modification of this notwithstanding it is simpler and is based on the same principle. Also in this case the ordinates represent the algebraic sum of the volumes of cuts and fillings, the cuts being considered as positive and the fillings as negative. The upper points of the various ordinates instead of being connected by means of straight lines or parabolic curves as in the Bruckner method are connected by horizontal lines drawn parallel to the ground-line. The so-called Lalanne's curve is really composed of a series of parallelograms above or below the ground-line, and it is very convenient for the location of the line of distribution and the calculation of the mean distance of hauling.

In Fig. 15, representing Lalanne's curve as given by Daries, he says that the volume BA of the cut should be carried on the equivalent volume Nh of fillings, and the mean distance for this partial hauling is Ah. If the hauling is smaller than 90 m. bar-

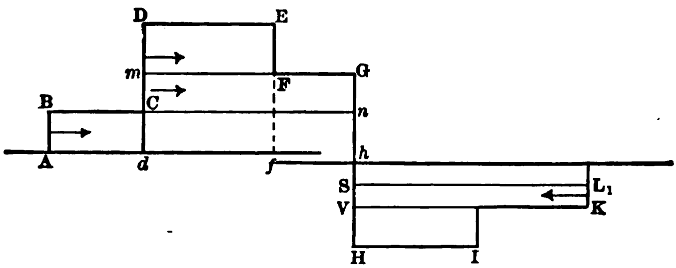


FIG. 15.

rows will be employed, otherwise the material will be transported by means of carts and wagons. Also the volume mC of cuts must fill in the equivalent volume Gn of fillings, and the partial mean distance of hauling is dh.

When Lalanne's curve ends above the ground-line, there is an excess Ll of fillings, which is necessary to build with materials taken from borrow-pits, but when the line of the curve ends on the ground-line this is the line of distribution of the volumes and the work will then be compensated.

The mean distance at which the materials ought to be hauled is usually calculated according to the following methods:

(1) By the horizontal distance of the projections of the centers of gravity of the cuts and fillings.

(2) By the moment.

(3) By Bruckner's and Lalanne's curves.

By the Projection of the Centers of Gravity.—The geometrical position of the centers of gravity of the cuts and fillings can be easily deduced from the longitudinal profile and cross-sections in the following manner. On a horizontal line lay off the distances of the various cross-sections, erect perpendiculars and on these take segments representing the excess of the cut or filling in the same cross-section; the segments indicating the cuts are marked above the horizontal line and those representing the fillings below. Unite all the points of the cuts and those of fillings, find the centers of gravity of these two figures, and the horizontal distance of their projection will represent in scale the mean distance of hauling. Only the difference between the cuts and fillings on the same section is marked here, because the earth removed from the cut and used for filling on the same section is not removed, and consequently it is only the surplus that must be hauled away.

The same result could be directly obtained from the graphical representation of the volumes of earthwork, as given on p. 23. By revolving the figures around the horizontal line and omitting the overlapping portions, which means to eliminate the areas of cuts and fillings compensated on the same cross-section, then the horizontal distance of the projections of the centers of gravity of the remaining areas will be the mean distance of hauling.

The horizontal distance of the projections of the centers of gravity of the cuts and fillings, however, represents the mean

distance of hauling only in case that the cuts and fillings are compensated. But when the cuts are in excess of the fillings or vice versa, and consequently the part in excess must be deposited in the waste-banks or taken from borrow-pits, the mean distance of hauling will then be given by the averages of the horizontal distance of the centers of gravity of the portions that are compensated and the horizontal distance of the projection of the centers of gravity of the excess of the cut and the spoil-bank as the defect of the cut and borrow-pit.

By Moments.—The second manner of calculating the mean distance of hauling is by moments. The name is borrowed from the mechanic, and means in this case the quantity of volume of earthwork included within two consecutive cross-sections multiplied by the distances at which this partial volume must be hauled. The mean distance of hauling will be obtained by the quotient of the sum of the moments of hauling divided by the sum of the hauled volumes.

On the application of this principle the mean distance can be correctly calculated by a very long process; but since in practical works the promptness of a method is always preferred to great mathematical accuracy, the mean distance of the hauling is obtained from the tables already given and especially constructed in order to know the distribution of the various masses of the earth along the line of the work.

According to the table used by the Italian engineers, illustrated at p. 33, the mean distance of hauling is obtained by the sum of the numbers in column 10, representing the partial products of the volumes to be removed, multiplied by the distance at which they ought to be hauled. Such a total, which in the case here considered is 94,498, must be divided by the sum of the numbers in column 8, representing the partial volumes 968. In this case the mean distance of hauling will be $\frac{94,498}{968} = 97$ meters.

French engineers considering separately the hauling done by means of wheelbarrow and that done by cart and wagon, two different mean distances are obtained, the one for the barrow,

and the second for the cart. In both cases, however, the mean distance of hauling is given by the sum of the products of the partial volumes by their distance, divided by the sum of the partial volumes. Thus the quotient of the numbers in columns 16 and 17, 2503 and 148,110 respectively, being 59, will represent in meters the mean distance of hauling by wheelbarrow; and the quotient of the numbers in columns 18 and 19, 2361 and 282,934 respectively, being 205, will give the mean distance of hauling by cart and wagon.

By Bruckner and Lalanne's Curves.—Both curves have been already explained at length, and consequently any further explanation will be useless. The area limited by the perimeter of the curve of Bruckner and the horizontal ground-line represents the moment of hauling of the volumes multiplied by the greatest ordinate, or the product of the volume multiplied by the mean distance; and consequently the mean distance of hauling is given by the total area divided by the greatest ordinate.

Similarly with the Lalanne's curve. Here the heights of the parallelograms are respectively equal to the algebraic sum of the cuts and fillings, while the bases of the parallelograms represent the partial distance of hauling. In this case also the general mean distance of hauling to be used in calculations will be given by the total area divided by the greatest ordinate.

CHAPTER IV.

CLASSIFICATION OF MATERIALS; ROCK EXCAVATION WITHOUT BLASTING.

CLASSIFICATION OF MATERIALS.

THE operation of destroying the cohesion of the earthy materials in order to remove them from their natural bed in the execution of work is termed excavation. These materials oppose a resistance to being moved which varies greatly with their nature. Some of them, as quicksand and mud, oppose little if any resistance, while others, as rock and indurated clay, oppose a very strong resistance. On the basis of resistance offered to excavation the earthy materials may be divided into two broad classes, earth and rock. On the same basis it is customary to divide both earth and rock into several subclasses.

Earth is usually divided into very loose soils, loose soils, and friable soils. The very loose soils are those which have so little cohesion that they offer practically no resistance to being separated from their natural bed, and may be removed by shovels; they are sand, mud, quicksand, peat, etc. Loose soils are those which have sufficient cohesion to make a stronger tool than a shovel necessary; the spade is necessary for their excavation. Clay, shale, gravel, and some sands belong to this group. The friable soils are those which require a sharp-pointed tool to break them up; the pick is the tool used in their excavation. Indurated clay, disintegrated rock, volcanic deposits, and agglomerated sands are considered friable soils.

Rock-like earth may be divided into three classes upon the basis of its resistance to excavation; these classes are soft rocks, rocks of ordinary consistency, and hard rocks. Soft rocks are

those easily moved by iron bars and wedges, and they comprise the slates and other stratified and easily split stones. The rocks of ordinary consistency are such as can be removed by iron bars, sledges, and channeling-machines, and among them are sandstones and various micaceous and talcose rocks. The hard rocks are those of such hardness and toughness that none of the tools mentioned are capable of breaking them up and blasting has to be resorted to. Generally in engineering work the softer rocks, which are capable of being excavated by tools, are blasted to shorten the time of excavation.

Because of the different degrees of resistance which different materials offer to excavation, the time required per unit volume for their excavation differs. These times are usually expressed in functions of a day's work, which is assumed to be ten hours, and by multiplying these numbers by the daily average of the workmen the cost of excavation per unit volume is at once known. The values of these functions are usually assumed to be as follows:

Very loose soils, including loading	0.07 to 0.09
Loose soils, excavation only	0.13 to 0.18
Friable soils, " "	0.20 to 0.25
Soft rock, " "	0.35 to 0.50
Ordinary rock, " "	0.75 to 1.00
Hard rock, " "	1.2 to 1.5

These figures serve merely to give a general idea of the time employed for excavating a unit volume; the engineer must make special estimates for any particular case. It is needful to note also that these data are for materials excavated in the open air, and must be modified when the excavation is done under difficult circumstances, as, for example, in tunnels, deep trenches, and shafts. For work done in tunnels the above coefficients should be multiplied by 1.5 for earth and by from 2 to 3 for rock.

In sinking shafts, where the work is still more difficult, the above coefficients should be doubled. In trenching, although the work is done in the open air, a change of the coefficients given is necessary, but it is difficult to say definitely how great this should be,

since local circumstances, such as the depth and narrowness of the trench, have a great influence. It can be assumed in a general way, however, that for trenches of ordinary size and depth these coefficients should be increased by quantities ranging from one-third to one-fourth of their value. Water increases the difficulty of excavation in trenches, and where surface-water, small springs, or seepage are present the coefficients given should be increased about 15 per cent.

In earthwork the quantities are always measured on the material in its original bed, and the coefficients which have been considered above refer to materials so measured. A cubic yard of earth or rock in its natural bed makes considerably more than a cubic yard of excavated material; generally speaking, the increase in volume is proportional to the resistance offered to excavation. It can be assumed as a general rule that for earth the increase is from 20 to 25 per cent., and for rock from 30 to 40 per cent.

The excavation of either earth or rock can be done by hand or by machine. In this and the succeeding chapters the tools and machines employed in earth and rock excavation are described and their use and operation explained.

ROCK EXCAVATION WITHOUT BLASTING.

From the early days of human civilization until very recently the excavation of rock was accomplished solely by means of hand-tools. Thus all the cut stones that were employed over 6000 years ago in the construction of the Pyramids and other Egyptian monuments, as well as the large stones used in the construction of the cyclopean walls which surrounded the prehistoric cities of Greece and Italy, were excavated by hand. For mining and engineering purposes, however, the excavation of rock was facilitated by suddenly cooling with water surfaces which had been previously heated by fire. On account of the sudden change in temperature cracks were produced which afforded points of attack by wedges and other sharp tools. Fire-

setting, as this operation was termed, was the only means of rock excavation, aside from hand-tools, which was employed up to the early part of the eighteenth century, as old engravings illustrating the mining operations of that time clearly indicate. It is still employed for breaking small boulders in contract work, and the author has witnessed its use on a large scale at the calcedony quarries near Sant Antonino di Susa in Italy to break up the rocks for the stone-crushers in making fire-proof bricks.

In 1613 the art of rock excavation was revolutionized by the introduction of blasting. In that year gunpowder, which up to that time had been used for artillery and other military purposes exclusively, was employed by a chief mining boss at Freiburg in Germany, for blasting the ore-bearing rock in the mines under his charge. Blasting by gunpowder was employed exclusively until the second half of the last century, when the discovery of nitroglycerine and its derivatives gave a more powerful explosive which has largely replaced gunpowder, although the latter is still used.

Rock may be excavated in two ways: (1) directly, by hand-tools and machine-cutting, and (2) indirectly, by blasting. Soft rocks and thin stratified rocks are generally excavated by hand-tools; it is only recently that rock-cutting machines have been generally employed. For excavating hard rock blasting is practically universal. In blasting, which is the process of shattering rock by the sudden generation of a large volume of gases in an enclosed space, several separate operations are required, viz., boring the holes, charging them with the explosive, tamping the opening, and firing the charge. The holes are bored to receive the charge, and the charge is the explosive matter from which the gases are developed; the tamping or closing of the holes above the charge prevents the gases from escaping without shattering the rock, and the firing is the act of igniting the explosive.

When rock is excavated by directly removing it from its natural bed by means of hand-tools or cutting-machines the tools most commonly employed are picks, crowbars, drill and hammer,

sledge-hammers, wedges, and the plug and feather; the only cutting-machine used in the excavation of rock for public works is the channeling-machine.

Pick.—The pick employed by the quarryman is similar to the one employed in the excavation of earth; it may have both ends pointed or one end may have a chisel edge. The points being wedge-shaped permit the tool to penetrate the joints or seams of fissured rock or between the laminæ of thinly stratified rocks, such as slates and shales. When its point has been forced into the rock the pick is used as a lever to increase the fracture by prizing upon the handle. Thus the action of the pick, as Mr. Lock says, embodies the actions of the hammer, the wedge, and the crowbar. It acts as a hammer in delivering a blow, as a wedge in penetrating and disrupting the rock, and as a crowbar or lever in forcing out large masses. When one of the points is chisel-edged the pick is used for cutting off the projecting corners and chips to smooth the walls of the excavation, but properly speaking it is not then an excavating-tool.

Crowbars.—The crowbar (Fig. 16) consists of an iron rod, an inch or more in diameter and 5 or 6 ft. long, which has one end shaped to a chisel edge and the other end bent to permit its use as a lever. Crowbars are used in excavating fissured or thinly stratified rocks. In operation the chisel edge is forced into the seams or between the strata, and the bar is swung back and forth, enlarging the opening. When the crevice is large enough the bar is reversed and the bent end inserted, after which the swinging back and forth is continued until the fragment of rock is detached from its bed.

Sledge-hammers and Wedges.—Rock is frequently excavated by means of sledge-hammers and wedges. The sledge-hammer (Fig. 17) consists of a parallelopipedon of iron with its extremities hardened, and having an eye at the center. Its weight varies from 30 lbs. to 50 lbs., and a wooden handle from 2½ ft. to 3 ft. long is inserted in the eye. The blow which can be struck with an implement of this character is very powerful. The sledge-hammer may be used alone or in connection with a wedge. They

are used alone for breaking masses of stone which have already been separated from their natural bed, and with wedges where the purpose is to separate a mass of rock from its bed. In breaking stones, if they are of moderate dimensions they are placed so as to be supported at the two ends, while the blow is delivered on the center. As a rule several blows are required, and each should be delivered on the same spot and at right angles to the quarry-bed. To break up rocks too large to be handled as just described

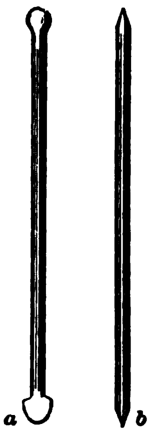


FIG. 16.

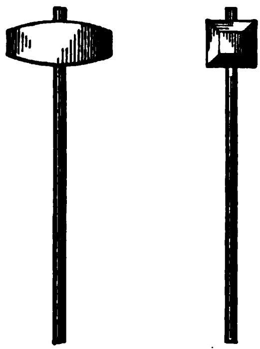


FIG. 17.

the projecting corners are first sledged off, and then a succession of blows delivered on the center of the remaining mass until it flies to pieces from the shock; or, if the mass is very large, it is split by means of the wedge.

Wedges of the form shown by Fig. 18 are, as a rule, made of iron and are about 1 ft. long and have a head 3×6 ins.; but sometimes, especially in the excavation of very soft and thinly stratified rocks, they are made of wood and with very much larger dimensions. Wedges are used mostly in cutting the rock from its natural bed, and the mode of procedure of this work is as follows: A slot is first cut in the rock by means of a pick or crowbar, and the wedge is inserted in this slot and driven home

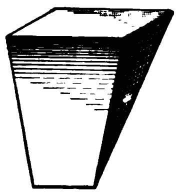


FIG. 18.

by blows with the sledge-hammer. By cutting a long slot, inserting a number of wedges at intervals and driving them simultaneously the rock can be split along a given line, and blocks of any dimensions ordinarily required thus broken out. Wedges are found most serviceable, however, when the dip of the rock is such as to permit their insertion between the strata so that the rock is split along its natural cleavage-lines.

Plug and Feathers.—For removing rock in blocks the plug and feather is a more satisfactory implement than a wedge. This method of excavation belongs more properly to quarrying than to ordinary excavation, but as in most engineering works where rock excavation is required there is masonry work which requires stones of regular shape, it is described here. The first operation is to drill a row of holes spaced at intervals along the line of the intended fracture. These holes may be drilled by hand or power drills, exactly as are holes for blasting as described in a succeeding chapter, but they are drilled only about a foot deep. In each hole are placed two feathers which are made of half-round wrought iron and is the form shown by Fig. 19. The plug is a piece of steel of the form of a truncated wedge, and it is placed between the feathers (Fig. 19) and driven tight. When the plug and feathers have been started in all the holes, the plugs are driven down simultaneously by light blows until the rock splits along the line of holes.

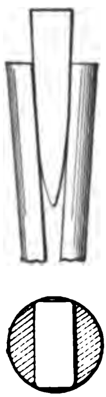


FIG. 19.

Channeling-machine.—The channeling-machine is a machine for cutting vertical slots or channels in rock, and a view of such a device at work is shown by Fig. 20. A vertical boiler is mounted on a car and supplies steam to a vertical cylinder, the piston-rod of which projects downward and carries a sort of cross-head to which are clamped the various cutting-tools. The car travels back and forth on a track parallel and close to the proposed cut, which is made by the tool or chisel receiving a reciprocating

motion from the motion of the piston in the steam-cylinder. The width of channel cut is usually 2¼ ins. at the top and 1¾ ins. at the bottom, the taper being found desirable in removing the chips and dust, which soon obstruct the tool by accumulation unless gotten rid of. This is frequently accomplished by flushing the channel with a jet of water. The cutting-bars used are of different lengths; the shortest is 2 ft. 10 ins., and it will cut a

FIG. 20.

slot 18 ins. deep, and the others increase in length successively, each cutting the slot 18 ins. deeper than the preceding. The edges of these tools are shaped in different ways according to the material to be channeled, and they are provided with shanks 1 in. thick and 6 ins. wide, by which they are attached to the cross-head. The largest cutter employed with this machine is 88 ins. long, so that the rock must be excavated in trenches from 7 ft. to 8 ft. deep. The work of the channeling-machine frees the rock from its natural bed, but only on its vertical sides; to free it from the bottom other means have to be adopted. For this purpose wedges are used, they being driven between the strata

if the rock lies in horizontal layers, or into the holes formed by a gadder if the rock is not stratified horizontally. The gadder is a machine by which a row of horizontal holes can be bored in line with the flow of the cutting.

The efficiency of the channeling-machine varies of course with the character of the rock being worked. In uniform sandstones it will cut about 500 sq. ft. of channel per day; in marble it will cut from 70 to 125 sq. ft. per day. In the excavation of the Chicago Drainage Canal, where channeling-machines were employed for the first time on a large public work, their capacity ranged from 50 sq. ft. per day in the moist material to 500 sq. ft. in the hardest and most homogeneous rock. It has been found by experiment that the most satisfactory depth of cut is between 6 and 10 ft., although this is considerably more than the average depth in quarrying.

Channeling-machines are built by the Sullivan Machinery Company of Chicago, Ill., and the Ingersoll-Sergeant Drill Company of New York, N. Y. The features of merit claimed by the makers and apparently proved in the construction of the Chicago Drainage Canal are convenience in operation, economy in fuel consumption, and efficiency. The cost of running a channeling-machine on this work was given by *Engineering News* as follows:

Wages of driver	$2.75
Wages of fireman	1.75
Wages of helper	1.50
Blacksmith and team for hauling drills	0.68
Superintendence	1.33
Cost of coal delivered to machine	2.50
Total	$10.51

The cost of working may be approximately learned from the following figures, referring to a fairly representative month's operation of an Ingersoll-Sergeant channeler on the Chicago Drainage Canal:

Driver's wages	$80.10
Helper's wages	39.30
Foreman's wages	48.58
Coal	80.00
Total	$247.98
Square feet channeled	4,020

From these figures the cost amounts to about 5 cents per square foot. This does not include the cost of blacksmith's work in sharpening tools; adding this and such other items as oil, stores, etc., the cost of the channeling work appears to have averaged 8½ cents per square foot, or 2.8 cents per cubic yard of excavation between the channels on opposite sides of the canal. All the other items, as repairs, interest on capital, sinking fund, etc., it may be safely assumed that the cost of channeling was 3 cents per cubic yard of material excavated.

CHAPTER V.

EXCAVATION OF ROCK BY BLASTING: THE DRILLING OF THE HOLES.

THE excavation of rock for the execution of public works is usually done by blasting. Blasting, as has already been explained, is the operation of shattering rock by the instantaneous generation of a large volume of gas in a confined space. Several different operations are required in blasting rock; the first is the drilling of holes into the rock, the second is the charging of these holes with an explosive, the third is the closing of the holes by tamping, and the fourth is the firing or ignition of the charge. These operations are described and explained in this and the two succeeding chapters.

HAND-DRILLING.

The drilling of the holes for blasting operations may be done either by hand or by machine-drills. Hand-drilling is employed where the quantity of rock excavated is so small that it will not pay to instal a power plant and employ machine-drills. The excavation of small trenches for pipes and conduits under city streets is an example of such a case. The tools used in drilling by hand are crowbars and hand-drills and hammers.

Crowbars.—The crowbar used in drilling is substantially similar to the one used in excavating rock without blasting, which has already been described. It is a steel rod $1\frac{1}{2}$ ins. in diameter and from 5 to 7 ft. long, the two ends of which are sharpened to a chisel edge. The manner of operating the bar in drilling is to raise it and let it fall vertically, turning it slightly in the hand at each blow. The continued repetition of blows drills the hole.

The chisel edge is made about 1 in. wider than the diameter of the shaft of the bar, so that the hole will be cut large enough to prevent any binding or wedging of the bar and thus permit it to fall freely. The object in turning the bar at each blow is to make it strike a fresh surface of rock. The hole is kept wet for the double purpose of preventing the heating of the bar and softening the rock. The chips and dust which accumulate in the hole must be removed frequently or else it will form a cushion which will stop further cutting of the rock. Scrapers are employed for removing these débris. These are iron rods $\frac{1}{4}$ to $\frac{1}{2}$ in. in diameter, with one end flattened and turned up to form a scoop. When being inserted in the hole the scraper is turned in the fingers so as to take on a load of chips and dust, which is then hoisted out of the hole by withdrawing the scraper. This operation is repeated until all the débris is cleared from the hole. Drilling by means of bars is very efficient in rocks of small tenacity, like sandstones and calcareous rocks. In these materials a man working 10 hours a day can drill from 5 to 15 lin. ft. of hole; for harder rocks the chisel or hand-drill and hammer are more efficient drilling-tools.

Chisel or Hand-drill.—The hand-drill (Fig. 21) is an iron or steel rod terminating at one end in a cutting edge and at the other end in a flat face to receive the blow of the hammer. As in the bar-drill and for the same purpose, the bit is made wider than the shank of the drill, this excess width varying with the depth of hole to be bored.

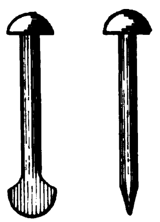


FIG. 21.

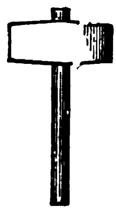


FIG. 22.

Hammer.—The hammer (Fig. 22) used with the hand-drill consists of a parallelopipedon of iron with steel ends, and an eye at the center to receive a handle. The length of the hammer-head is usually from 6 to 8 ins., and it has a cross-section from $2\frac{1}{2}$ to 3 ins. square. The handle is usually about 18 ins. long. The total weight of the hammer is about 5 lbs.

Method of Operation.—The manner of operating the hand-

drill and hammer is as follows: Holding the drill against the rock and in his left hand, the driller strikes its head with the hammer; he then raises and turns the drill slightly and repeats the blow. This process is continued until the hole reaches the required depth. As in bar drilling, the hole is kept wet and the chips and dust are removed at intervals with a scraper. This method of drilling is very slow, and should be used only where a few isolated holes are to be drilled or where an occasional boulder is encountered and has to be removed by blasting. Where a considerable number of holes have to be drilled the preferable practice is to employ three men to each drill, one man manipulating the drill and the other two striking it with sledges like that already described but weighing only about 10 lbs. and having longer handles. The drills used vary in length from 2 to 10 ft. Usually the men alternate in holding the drill, and the blows are delivered alternately by the two strikers. With expert workmen the steadiness and regularity of the blows is quite remarkable, the click of the hammers being as steady and monotonously regular as the tick of a clock. The progress of work with hand-drills and hammers varies with the character of the rock.

MACHINE-DRILLING.

The drilling of the holes for blasting operations is more usually performed by machine than by hand. Several forms of rock-drilling machines or power drills have been devised, but they may all be classed either as percussion drills or rotatory drills. Percussion drills, as their name indicates, operate by striking a series of sharp rapid blows, while the latter operate by a true boring action like a carpenter's augur.

Percussion Drills.—A percussion drill may be described as a machine designed to operate a drill-bar with a reciprocating motion so that it alternately strikes and withdraws from a rock surface to be drilled. The operating mechanism may be a piston working in a cylinder or it may be any other mechanism capable of producing a reciprocating motion. Besides giving the necessary reciprocating motion the operating mechanism must gradually

rotate the drill so that a fresh surface is always presented to the cutting edge, and it must also advance the drill as the hole deepens. We shall discuss first the piston-driven form of drill, and afterwards other forms.

While piston-driven drills are usually operated by compressed air, they can, by slight modifications of detail, be operated by steam. This latter is the power usually employed in contract work and open excavation. Compressed air is preferred for mines and underground quarries, and where a large number of drills are supplied from one plant. The term "rock-drill" is almost universally adopted for drills of piston type whether air- or steam-driven. The various drills on the market are practically identical in principle, and differ only in construction details, valve actions, and the materials used. No machine is subject to more severe service, and selection should be based upon running qualities, cutting capacity, and endurance.

Fig. 23.

The rock-drills of the Ingersoll-Rand Company may be taken as typical of this class of machinery. They are made in two types, distinguished by the valve movements. Fig. 23 illustrates the Sergeant "Auxiliary Valve" drill, mounted on a tripod. This has the usual drill-cylinder, sliding in a guide-shell under control of a feed-screw manipulated by a crank. The shell in time is mounted on the tripod saddle. This drill has an air- or steam-thrown valve of spool type. Pressure is admitted to throw this valve by a small arc-shaped auxiliary valve which is struck and

moved by the piston in its travel. The advantage of this valve movement is that while the main valve is balanced and independent of the piston, it is positively actuated whatever the stroke. The main valve action is independent of the condition of the cylinder-bore or the fit of the piston. The stroke is variable from a minimum of about 2 inches up to the maximum of the drill. The blow struck is absolutely uncushioned, and this drill is adaptable to rock of every degree of hardness and every quality and structure.

Fig. 24 illustrates the Rand "Little Giant" drill. This is a tappet-valve type, i.e., the main valve is mechanically thrown by a tappet, or rocker, which is struck by the piston. The valve in this drill is balanced and free from excessive wear due to pressure. This drill is peculiarly effective where steam is to be used, especially if wet steam and low pressure only are available.

FIG. 24.

The manufacturers claim that an exclusive feature of especial value in these two drills is the "release rotation," which frees the rifle-bar when the steel sticks in the hole and thus prevents broken rifle-bars, twisted steels, and broken shanks. Another marked feature in the drills of this company is their perfect simplicity, the absence of complication laying them open to injury. Endurance is secured by the use of iron and steel of extra quality and special treatment.

The tripod mounting is the one usually employed in open excavation, as quarries, railway cuts, contract work, etc. In the

mine and tunnel drills, the tunnel column (vertical) and the shaft-bar (horizontal) are the usual mountings.

The size of a drill is usually designated by its cylinder diameter. The makers in question further use a size letter which distinguishes the limits of size, giving a certain flexibility within these limits. The following table from the Ingersoll-Rand Company gives the more important data regarding their drills.

Size Letter.	Cylinder. Diameter.	Cylinder. Stroke.	Maximum Advisable Depth of Hole.	Diameter of Hole.	
	Inches.	Inches.	Feet.	Inches.	
A	2–2¼	5	5	⅝–1½	These s zes are for common use in mine, tunnel, quarry, aud open-cut excavation.
B	2½	6	9	1 –1½	
C	2¾	6½	10	1¼–2¼	
D	3	6½	14	1½–2¼	
E	3¼	6½	16	1¾–2¾	
F	3½	7	20	1¾–3	
G	4¼	9	27	3 –6	These sizes are for the heaviest work in contracts and submarine excavation.
H	5–5½	8	32	3 –6	

The efficiency of the air-drill varies with the character of the rock. Manufacturers generally state that the average work per ten-hour day drilling holes downward and including the time lost in setting up the drill and changing the bits may be assumed to be from 50 to 75 ft. of hole. The writer, however, kept records for nearly six months of the daily work performed by ten air-drills working on the mica-schist rock of New York City, which is much softer than granite, and found the average ten-hour day's work to be 45 ft. On one occasion a drill made 72 ft., but this was an exceptional instance and was the maximum record made by any of the ten drills observed. The horse-power required to operate an air-drill is from 8 to 10 H.P. per hour, according to the size of the drill, and consequently a portable steam-boiler cannot operate more than four drills.

A blacksmith-shop is a necessary adjunct to a plant of air-

drills, as the bits have to be frequently sharpened, especially when the work is in granitic or feldsparitic rock. A blacksmith with a boy helper can sharpen the bits for four drills. Each drill is operated by two men, and its running expenses are composed of the following items:

One-fourth of the daily expense of the boiler, fireman included	$2.20
One-fourth the blacksmith-shop expenses	1.30
Two operators, at $2 per day each	4.00
Total expense	$7.50

This sum divided by the number of feet drilled per day gives the cost per lineal foot drilled. This, in the case previously mentioned as recorded by the author, where the drills averaged 45 ft. per day, was $\frac{7.5}{45} = .166$ per foot. To this must be added the maintenance, interest on investment, and sinking fund.

The preceding remarks have referred to piston-drills operated by steam or compressed air. Recently electrically operated percussion-drills have been put on the market and are considerably employed in some Western mines. The general appearance of these electric drills is much the same as that of air-drills, and in fact air-drill standards are followed in all possible features. Several manufacturers are already turning out electric drills, all of which are constructed on the same principle. The following is a description of the Durkee electric drill, taken from the *Engineering News:*

The Durkee drill here illustrated (Fig. 25) is operated by a flexible shaft, which is in effect several coil springs wound in opposite direction, one over the other. This shaft is driven by a portable electric motor of 1½ H.P. The shaft is attached to a bevel-gear driving a crank-shaft, *A*, which passes through the drill-casing. The crank-pin works in the slotted horizontal arm of the bell-crank lever, which is mounted on a shaft journaled

in the casing. The vertical arm straddles the drill-rod and is fitted to trunnions on a casting which slides on the rod. Between this casting and collars on the rod are coiled springs through which the power is transmitted for movement of the rod in each direction. The parts are so proportioned as to give a sharp

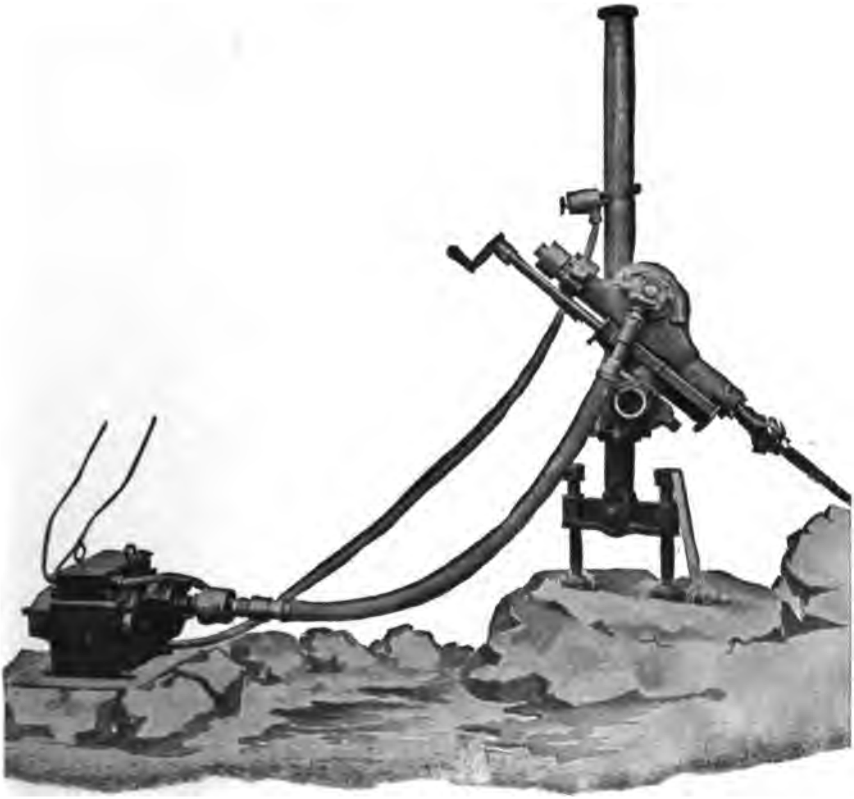


FIG 25.

cutting stroke and a slower return stroke, while a flywheel, on the crank-shaft also provides for uniformity of action. At the heel of the rod is a rifled section, or ratcheted rod, working in a rifted nut by which the required rotary movement is given to the drill-bit. The rotating device and the chuck are the same

as in compressed-air drills of the ordinary type. The cylindrical casing is fitted to a slide or feed-table operated by a feed-screw and crank-handle in the usual way, and this table is mounted either upon a column, tripod, or bar, according to the requirements of the work. The machine makes about 580 strokes per minute, and its weight, exclusive of the tripod or other support, is about 230 lbs. A number of machines are now in use in mining operations, and they are introduced by the Mine and Smelter Supply Company of Denver, Col.

The Marvin Electric Drill Company of Binghamton, N. Y., manufacture a percussion drill depending for its operation upon the well-known solenoid principle. Referring to cross-section of the drill (Fig. 25*a*), the part marked 3 is a double solenoid inside of

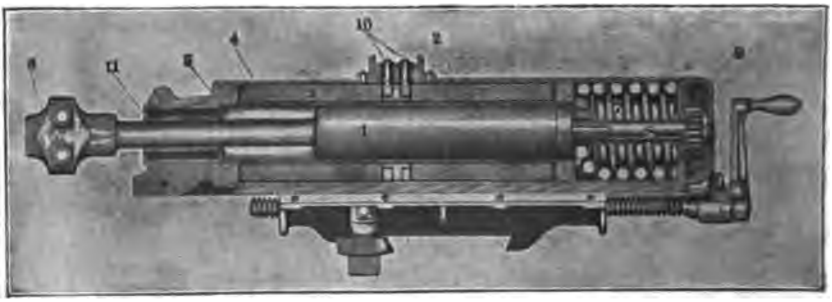


FIG. 25*a*.

which the active part, corresponding to the piston of an air-drill, is free to move. A special current is supplied to this double solenoid in such a manner as to cause this working part to reciprocate. The drill is mounted on a tripod, and it differs very little in appearance from an ordinary air-drill. The absence of motor, rheostats, starting-box, cranks, shafts, gears, cams, packed joints, close fits, stuffing-boxes, and exhausts is always appreciated in coming in contact with this machine. It has been on the market for some time, and is now offered in three sizes for holes down to 4′, 8′, and 16′ respectively.

Rotary Drills. — Rotary drilling-machines are very seldom employed in ordinary excavations, although they are extensively used in tunneling and prospecting, and consequently their use

among contractors is very limited. Rotary drills, as the name indicates, bore holes by rotation; that is, a core of rock is cut out by a hollow cylinder provided with a cutting edge having a rapid rotary movement and pressed with great force against the rock. On this principle two kinds of machines are built, diamond drills and those with hardened steel bits.

Diamond drills consist of a hollow bit on the cutting edge of which there are diamonds set in such a manner that they are the only part of the tool coming in contact with the rock (Fig. 26). An essential feature of these machines is a stream of water forced through the interior of the bit for the double purpose of keeping the bit cool and the hole clear of sediment, which is forced out by the pressure of the water. Diamond drills bore perfectly straight, smooth holes to any depth or in any direction from vertical to horizontal, bringing to the surface a solid section or *core* of all strata passed through, showing their exact depth, thickness, and the character of the rock. For these reasons they are commonly employed in prospecting and for geological purposes; but they could be also employed with great advantage by engineers and contractors before undertaking rock excavation of importance in order to determine both the nature of the soil and the thickness and direction of the strata to be met with. In such cases the hand diamond drill capable of boring 1½-inch holes and taking out 1-inch cores, will be found very useful.

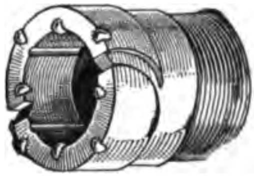


FIG. 26.

The machine is mounted on hollow standards, with hollow back braces, thus combining strength, rigidity, and light weight. Two cranks, one on each side of the standard, moved by hand and engaging a system of cog-wheels, impart a rapid rotary movement to the shaft and consequently to the bit. The pump furnished with this machine is mounted on one of the columns as shown in the cut, and is worked by an eccentric on the main crankshaft. The lifting apparatus is mounted on the back braces. It consists of a drum wound with wire rope, and the rods are

raised by hand-power with rope and blocks. With this simple machine holes can be bored to a depth of 300 ft., and it is operated by only two men, who may transfer it where required, since the total weight of the machine is only 190 lbs. Fig. 27 shows a small Rotary Diamond Drill operated by steam as constructed by the Sullivan Company of Chicago.

FIG. 27.

Owing to the great rise in the price of diamonds, the cost of extracting cores by the diamond drills has recently been greatly increased, and consequently resource was had to a new drill provided with a hardened steel bit. It was invented by Mr. F. Harley Davis, an Australian engineer, and introduced in the United States by the Davis Calix Drill Company of New York City.

This machine, both in general appearance and manner of working, is similar to the diamond drilling-machine, with the difference that the cutting, instead of being done by diamonds, is performed by means of steel teeth of special construction, as indicated by Fig. 28. The teeth are $2\frac{3}{8}$ ins. long, $\frac{7}{16}$ in. thick, and $1\frac{1}{4}$ ins. wide; they are straight on the cutting edge, with the back at an angle of 30° or 35°; between each tooth there is a groove. When the teeth wear down to a length of 2 ins. they need to be recut. The Davis cutter has a sort of hammer and chisel action, cutting the rock into small chips.

The Davis Cutter.

FIG. 28.

A peculiar feature of this drill is the calix, shown in Fig. 29, whose office is to receive the chips of the rock and hold them until they are removed with the core. The ordinary method of operating the drill is very simple. Power is

received through a horizontal shaft and is delivered by bevel-wheels to a horizontal wheel which grips the drill-rod by suitable mechanism. Water is furnished to the drill-rod from a pump by means of a hose. A hook inserted at the top of the drill-rod is for the purpose of hoisting the drill-rod, with its attached cutter and calix, together with the core of rock from the bore.

The Davis cutter, although it cuts almost any kind of rock, is very efficient for boring through sandstones, hard shales, and similar soft rocks. These have been penetrated at the rate of ¾ in. per revolution of the cutter. The drill is manufactured in different sizes, capable of taking out cores from 2⅜ to 10¼ ins. in diameter. In New York a core of 10 ins. in diameter was

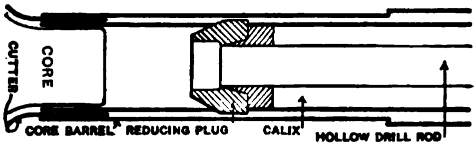


FIG. 29.

taken from a bore-hole 11¼ ins. in diameter, drilled for the Stokes Apartment Hotel at Seventy-fourth Street and Broadway.

Rotary drills have not so far found general employment on public works; an exception, however, should be made for the Brandt's hydraulic drilling-machine, which has been somewhat extensively used in the more recently excavated Alpine tunnels of Continental Europe. The Brandt hydraulic machine was invented by Mr. A. Brandt, and it was employed for the first time in the excavation of the Sonnenstein tunnel along the Gemünden-Ebensee R. R. in the year 1877. The Brandt machine received a fair test in the Pfaffensprung tunnel of the St. Gothard R. R., and since then it was employed as a substitute for the percussion drilling-machine in the Arlberg and Brandleite tunnels, and it is now the only drilling-machine used in the excavation of the Simplon tunnel.

The Brandt machine consists of a four-wheeled carriage supporting at the center a beam provided with two arms of different

length; the short arm carries the boring mechanism, while the longer one is provided with a counterpoise. The distributor is located near the center of the beam. The short arm is furnished with a clamp holding the butting column, which is a wrought-iron cylinder with a plunger constituting a ram, and is jammed by hydraulic pressure between the walls of the heading of the tunnel, thus forming a rigid support for the boring-machine and an efficient abutment against the reaction of the drill. This butting column can be rotated on its clamp in a plane parallel to the axis of the beam. Three or four separate boring-machines can be mounted on the column and can be adjusted in any reasonable position.

The boring-machine performs the double function of continually pressing the drill into the rock by means of a hollow ram (1) and of imparting to the drill and ram a uniform rotary motion. This

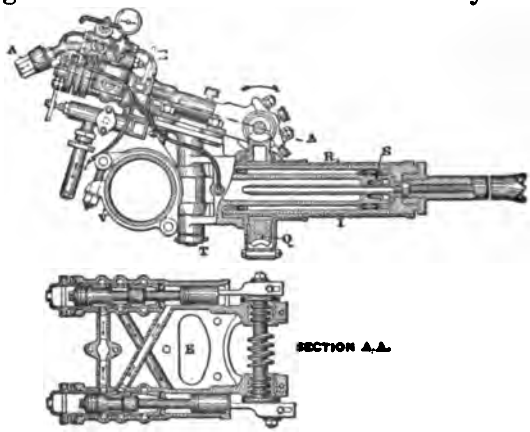


FIG. 30.

rotary motion is given by a twin-cylinder single-acting hydraulic motor (*E*), the two pistons, of $2\frac{3}{8}$ ins. stroke, acting reciprocally as valves. The cranks are fixed at an angle of 90° to each other on the shaft, which carries a worm, gearing with a worm-wheel (*Q*) mounted upon the shell (*R*) of the hollow ram (1), and this shell in turn engages the ram by a long feather, leaving it free to slide axially to or from the face of the rock. The average speed of the motor is 150 to 200 revolutions per minute. The loss of power between the worm and worm-wheel is only 15

per cent. at the most; the worm being of hardened steel and the wheel of gun-metal, the two surfaces in contact acquire a high degree of polish, resulting in little wearing or heating. Taking into consideration all other sources of loss, 70 per cent. of the total power is utilized. The pressure on the drill is exerted by a cylinder and hollow ram (*l*) which revolves about the differential piston *S*, which is fixed to the envelope holding the shell *R*. This envelope is rigidly connected to the bed-plate of the motor, and by means of the vertical hinge and pin *T* is held by the clamp *V* embracing the butting column. When water is admitted to the space in front of the differential piston the ram carrying the drilling-tool is thrust forward, and when admitted to the annular space behind the piston, the ram recedes, withdrawing the tool from the blast-hole. The drill proper is a hollow tube of tough steel 2½ ins. in external diameter, armed with three or four sharp and hardened teeth, and makes from 5 to 10 revolutions per minute, according to the nature of the rock. When the ram has reached the end of the stroke of 2 ft. 2½ ins., the tool is quickly withdrawn from the hole and unscrewed from the ram; an extension rod is then screwed into the hole and into the ram, and the boring is continued, additional lengths being added as the tool grinds forward; each change of tool or rod takes about fifteen to twenty-five seconds to perform. The extension rods are forged steel tubes fitted with four-threaded screws, and having the same external diameter as the drill. They are made in standard lengths of 2 ft. 8 ins., 1 ft. 10 ins., and 11¾ ins. The total weight of the drilling-machine is 264 lbs., and that of the butting column when full of water is 308 lbs. The exhaust-water from the two motor cylinders escapes through a tube in the center of the ram and along the bore of the extension rods and drill, thereby scouring away the débris and keeping the drill cool; any superfluous water finds an exit through a hose below the motor and thence away down the heading. The area of the piston for advancing the tool is 15½ sq. ins., which, under a pressure of 1470 lbs. per square inch, gives a pressure of over 10 tons on the tool, while for withdrawing the tool 2½ tons is available.

In the gneiss rock found at Isella on the Simplon Tunnel, a hole 2¾ ins. in diameter and 3 ft. 3 ins. in length is drilled normally in twelve minutes to twenty-five minutes. The time taken to drill ten to twelve holes 4 ft. 7 ins. deep is two and one-half hours. By means of this machine a daily advance of 18 to 19 ft. 6 ins. is made in a heading having a minimum cross-section of 59 sq. ft.

FIG. 30*a*.

Still another machine has been lately introduced in public works for drilling holes of larger dimensions, chiefly used to prepare for the blasting of loose soils where large quantities of explosive of the lowest efficiency are required. The machine, of the percussion type, can be compared to a very heavy churn-drill, lifted by steam-power, and striking the soil by its own weight. The drill is made up of different parts, as the bit, the drill-stem, and the rope-socket, screwed together so as to form a solid bar of steel over 300 lbs. in weight. The machine is mounted on a truck provided with a boiler and an engine. An A frame mounted at the rear end of the truck carries on top a sheave over which passes the Manila rope. The drill is lifted by winding the rope around the drum of the engine, and then it is released all at once so that it will strike the ground with great force, descending rapidly on account of its weight. Fig. 30*a* indicates one of these machines as built by the Keystone Driller Company of Beaver Falls, Pa.

CHAPTER VI.

ROCK EXCAVATION BY BLASTING; EXPLOSIVES AND THEIR TRANSPORTATION AND STORAGE.

In the excavation of rocks by blasting the operation which follows the drilling is the filling of the drilled holes with the blasting charge. This consists of an explosive substance, which is a chemical compound of such composition that when ignited it undergoes a sudden transformation into gas occupying many times the space of the original compound. The most important substances employed as explosives are gunpowder, nitroglycerine, and dynamite.

Gunpowder.—Gunpowder was discovered in Germany about the year 1320 by Berthold Schwartz, a monk of the order of St. Augustine. In reading the magnificent synopsis of the history of explosives given by Drinker in his work on tunneling, it seems that gunpowder was known long before the generally accepted data of its discovery by Schwartz. There is no doubt, however, that it was only after his time that gunpowder came into practical use and was a substance well known to the scientific world. It is composed of charcoal, sulphur, and saltpeter in different proportions according to the use it is intended for; thus for mining purposes its composition is as follows: 65 per cent. saltpeter, 15 per cent. sulphur, and 20 per cent. charcoal. It is a black granulated substance and when ignited burns, developing gases amounting to 280 times its former volume. Gunpowder is ignited by the application of any substance heated to redness; flame alone will not so readily ignite it.

The nature of the gases developed by gunpowder have not yet been ascertained. It is, however, generally admitted that

the oxygen of the saltpeter converts nearly all the carbon of the charcoal into carbonic acid, CO_2, a portion of which combines with the potash of the niter to form carbonate of potash (K_2OCO_2), the remainder existing in the state of gas. The sulphur is converted into sulphuric acid (SO_3) and forms sulphate of potash, which by reaction is decomposed into the hyposulphate and sulphide. The nitrogen of the saltpeter is almost entirely evolved in the free state, and the carbon not burnt into carbonic acid remains and forms oxide of carbon, which always accompanies the explosion of gunpowder.

The force of the gases produced by the ignition of gunpowder has been variously estimated at from 15,000 to 200,000 lbs. per sq. in. A discussion of this question is given by Mr. Lohr in the article "Explosives" in the *Spon's Engineering Encyclopedia*. The experiments of Nobel and Able, Mr. Lohr says, have shown that the explosion of gunpowder produces about 57 per cent. by weight of solid matters and 43 per cent. of permanent gases. The solid matters are, at the moment of the explosion, in the fluid state. When in this state they occupy 0.6 of the space originally filled by gunpowder; consequently the gases occupy only 0.4 of that space. These gases would at atmospheric pressure and 32° F. temperature occupy a space 280 times that filled by powder. As they are compressed into 0.4 of that space, this would give a pressure $\frac{280}{0.4} \times 15 = 10{,}500$ lbs., or about 4.68 tons per square inch. But a great quantity of heat is liberated in the reaction and this heat will enormously increase the tension of the gases. The experiments of Nobel and Able showed that the temperature of the gases at the instant of the explosion is about 4000° F. Thus the temperature of $32° + 461°.2 = 493°.2$ absolute has been raised $\frac{4000}{493.2} = 8.11$ times, so that the total pressure of the gases will be $4.68 \times 8.11 = 37.9$ to the square inch. That the pressure of 37.9 tons to the square inch is not exaggerated is shown by the fact that there are experiments indicating that the pressure of the gases was as high as 42 tons to the square inch.

Nitroglycerine.—A more modern explosive used as a substitute of gunpowder in the excavation of rock is nitroglycerine, discovered by Sobrero in the year 1847. Nitroglycerine is obtained either by the action of concentrated nitric acid on glycerine, or by a mixture of nitric acid at 40° and sulphuric acid at 66°, on glycerine. Its reaction can be represented by the formula,

$$\underset{\text{glycerine}}{C_3H_8O_3} + \underset{\text{nitric acid}}{3HNO_3} = \underset{\text{nitroglycerine}}{C_3H_5O_3.(NO_2)_3} + \underset{\text{water}}{3H_2O}.$$

The sulphuric acid which is mixed with the nitric does not enter into the reaction, but absorbs the water which is set free. Nitroglycerine is a clear yellow, oily liquid with a sweet taste but no odor; it is poisonous when inhaled or simply introduced into the body through the pores, producing headache and sickness. Its specific gravity is 1.595. Nitroglycerine burns very quietly in contact with ignited bodies, but it explodes at a temperature of 388° F. Its explosion is caused by the slightest percussion, and this makes its handling very dangerous. Nitroglycerine freezes at 41° F., and although it explodes very easily by percussion in its normal state, it explodes with great difficulty when frozen; hence in America, at the beginning of its use, nitroglycerine, as well as all the other explosives containing it, were transported only in a frozen state. When nitroglycerine contains some impurities or is not well washed off, it undergoes spontaneous decomposition, accompanied by development of gases and increase of temperature, which, in reaching 388° F., causes its explosion.

There are no complete experiments upon the pressure of the gases generated in the explosion of nitroglycerine. Mr. Nobel estimates the strength of nitroglycerine as 4 times that of gunpowder—and the relative strength, bulk for bulk, since the specific gravity of gunpowder is 1 and nitroglycerine 1.6, as 5.91 times that of gunpowder. This is a very important feature in rock excavation, because with a given height of charge in a bore-hole, nitroglycerine exerts about 5¾ times the force of gunpowder.

Notwithstanding its enormous strength nitroglycerine is never employed in its liquid state for rock excavation, but is always mixed with some other substance which renders its handling less dangerous.

Dynamite.—Any mixture of nitroglycerine with an absorbent substance which reduces it into a solid mass is called *dynamite*. It is on account of this simple transformation that the explosives containing nitroglycerine have been so extensively used in practical works. In regard to the nature of the absorbent substance, dynamite is divided into two classes—true and false dynamite.

Dynamite was discovered in 1865 by Prof. Nobel. He mixed nitroglycerine with a siliceous sand called kieselguhr, found at Oberlohe near Unterlau, Hanover. It is a white, siliceous, soluble substance, composed of microscopic shells of diatomæ, which are endowed with great strength and an enormous power of absorption of liquid in proportion to their size; they will absorb 75 per cent. of nitroglycerine. In being absorbed, nitroglycerine does not undergo any chemical change; it burns, freezes, and explodes under the same conditions as in the fluid state. Dynamite is easily handled and transported without danger, but explodes with more difficulty by percussion.

During the explosion of the nitroglycerine contained in dynamite some oxygen is set free, and in order to utilize it, it seems logical to use as an absorbent matter able to burn at the moment of the explosion, thus increasing both the quantity of gases and the heat produced, and consequently increasing also the efficiency of the dynamite. Under the general name of false dynamite are included all the various nitroglycerine explosives in which the absorbent substances, instead of remaining inert during the explosion, liberate gases, thus greatly increasing the efficiency of the dynamite. When the new substance introduced into the composition of dynamite is able to generate a large volume of gases, compounds of greater efficiency are obtained.

Nearly all the explosives with fancy names which are placed on the market by different manufacturers are simply false dynamites. Thus, for instance, the *Lithofacter* manufactured by

Krebs at Cologne is composed of 52 parts of nitroglycerine, 30 of fine sand, 12 of charcoal, 4 of nitrate of potash, and 2 of sulphur. In a word, he uses gunpowder as an absorbent, and the sand to give weight to the compound. The Forsyte dynamite which has been so extensively used in the rock excavation for the New York Subway is a false dynamite composed of nitroglycerine, sawdust, and nitrate of soda, and a little white of lead for weight.

Nearly all manufacturers of explosives make a secret of the ingredients entering into the composition of their products. To make a secret of the ingredients, even if it be necessary for commercial purposes, does not speak well of the product, and engineers and contractors should always refuse to buy products that they do not thoroughly know, especially when the work is to be done in a close space, as in tunnels and mines. It has been already remarked that the nitroglycerine produces a poisonous effect upon men; but the gases generated by its explosion are not poisonous but simply asphyxiating. It is, however, impossible to know the effects of the gases produced by the other substances introduced if these are not known. Doctors have noticed the poisonous effects of nitroglycerine upon the men working in the Croton Aqueduct tunnel. In an article published in the *Scientific American Supplement* it is stated that since were found the men working in the tunnel affected by the same symptoms as those produced by pure nitroglycerine, the cause must be that, mixed with the gases produced in the explosion, there are unexploded particles of nitroglycerine in a volatile state, and these particles inhaled by miners affected their health. If the doctor's conclusions are true it means that only part of the nitroglycerine exploded, and consequently only part of its force was utilized; hence the explosive was not very efficient; or else the poisonous effect was due to the presence of gases generated by unknown substances which produced the same symptoms as the inhalation of nitroglycerine. In any case such an explosive should be discarded by the contractors, because either it is not efficient, or by affecting the men, they will work under abnormal conditions and their work will be dearer in the end.

The explosive power of dynamite has not yet been correctly determined. In the few experiments made for calculating the force of various explosives, the force of gunpowder is taken as unity. Mr. Nobel tried to compare the force of the various explosives by loading a mortar with a 32-lb. shot and calculating the distance of the shot, the mortar being inclined at an angle of 10°. Weight for weight he deduced the comparative forces of the various explosives as follows: Gunpowder, 1; dynamite, 2.89; nitroglycerine, 4. Comparing these explosives bulk for bulk, the specific gravity of dynamite being 1.65 of the gunpowder, they range as follows: Gunpowder, 1; dynamite, 4.23; nitroglycerine, 5.71. These figures mean that 1 lb. of dynamite will produce a force 4¼ times greater than that produced by 1 lb. of gunpowder.

In artillery the force of the various explosives is usually calculated by a specially constructed gun in which, close to the charge, there is a bell of the same metal forged with the gun. The bell is filled in with a plug of lead or other soft metal. In the explosion, the gases will compress the lead, and by measuring the plug before and after the explosion it is known how much it was compressed. By placing a similar plug of lead in a testing-machine the force required to compress it an equal amount is determined and from this is deduced the force per unit of surface exerted by the gases during the explosion.

TRANSPORTATION AND STORAGE OF EXPLOSIVES.

In Continental Europe, on account of the constant fear of political rebellions and anarchist attacks on persons and property, the manufacturing, storing, transporting, and sale of explosives are regulated by special and strict laws and are under the rigid surveillance of the government. In the United States anybody is free to manufacture explosives after obtaining a special permission from the State, which is given upon guarantee that in case of explosion no serious damage will result to persons and property outside the factory. For this reason factories are

located in the open country and in some isolated spot far from towns and villages or even farm-houses.

Transporation of Explosives.—The laws regulating the transportation of the explosives on European railroads tend to detect the existence of any clandestine factory and to avoid as much as possible the causes of explosion, thus reducing the danger to persons and property. The detection of the unauthorized factories is obtained from the fact that no explosive can be shipped on any railroad or vessel if it is not produced by a national factory working under the government permission. In case the explosive to be transported was produced in a foreign country, it must be accompanied by a special permission of the national government, which is given only in case that the factory was duly authorized and is working under the surveillance of the foreign government in whose jurisdiction the factory is located. The explosives must be packed according to a prescribed manner and the boxes must have on the cover a detailed description of the contents, the weight of the explosives, the name of the manufacturer, and the location of the factory.

The laws which tend to avoid or at least to reduce to a minimum the danger of explosion during transportation of explosives are very numerous. Since explosion can result either from fires or by percussion, the laws prescribe rules tending to avoid accidents produced by these causes. To avoid fires it is prescribed that the explosives be transported in separate and sealed cars, in which no more than a prescribed quantity can be placed at a time. In cars containing explosives, fires, lights, and smoking are absolutely forbidden. The cars must neither be attached to the train close to the locomotive nor near cars containing inflammable materials, and the loading and unloading of these cars must be made in the daytime, it being absolutely prohibited at night. To avoid the danger of explosion by percussion it is generally prescribed that all materials must be so well packed as to entirely fill the box without leaving any void; that the boxes, barrels, etc., containing the explosives must be so tightly

packed into the cars that even the slightest movement is impossible; that boxes shall not contain nails or iron bands, and finally the use of hammers, chisels, and other iron and steel tools inside the cars is forbidden. The boxes containing detonators must be stored in separate cars from those containing explosives. The regulations for the transportation of the explosives upon ordinary roads go into even more detail, so as to describe even the form of the brake to be used in the cars in going down-grade, where to stop at night, the manner of making short stops within the city limits, how to cross villages and towns, the streets to be avoided and those through which it is allowable to pass, and a thousand of other details. When the transportation of the explosive is made on water by means of vessels some governments compel the vessel to carry a special flag and night signal so that it can be recognized from far away.

In this country there are no special laws for the transportation of explosives; every railroad company, however, enacts special rules so as to insure itself against the liability of paying great damages to persons or properties in case of explosion. These special and various regulations are based upon the same principle as the European laws, the only difference being that they are inspired by the desire for safety and not by any fear of rebellion or conspiracy, and consequently all the obstructive rules regarding this point are here happily omitted.

Storage of Explosives.—The storage of explosives is regulated by laws which are too strict and antiquated. The writer has remarked in *Engineering* that in the city of New York the laws allow only a maximum deposit of 62½ lbs. of dynamite, while on the other hand, the same city compelled one of the sub-contractors of the rapid-transit railroad to use not less than 500 lbs. of dynamite per day, which could be stored at only two points. This means that even in the city of New York the law regarding the storage of the explosives is antiquated and entirely insufficient to meet the requirements of works of the magnitude undertaken to-day.

The regulations governing the storage of explosives tend to

prevent the causes of explosion, and are designed so that in case of an accident the explosion produces the smallest damage possible under the circumstances.

Large quantities of explosives are usually stored when the daily quantity of them to be employed in the work is great and the supply cannot be obtained every day, but at great intervals from one consignment to another. Such a large deposit of explosives should be very carefully watched to avoid the causes producing explosions, which are spontaneous decomposition of the ingredients contained in the explosives, fire, and percussion. To prevent the decomposition of the substances forming the explosives it is necessary to locate the store in a very dry place, and the temperature inside the room should neither fall below 8° C. nor be higher than 30° C. The explosives must be stored in their original packages as they came from the factory, with the difference that the cover of the boxes should be raised so as to expose the explosive to the air and so that they can be easily watched and any alteration detected. The decomposition of nitroglycerine products is generally detected by a kind of perspiration which collects on the outside wrappers of the explosive. The boxes containing explosives thus affected should be taken out of the storage immediately and opened. These boxes should then be carried to a distant isolated place and the explosives, liberated of their wrapping, should be spread on the ground, forming a very thin stratum, and burned. Nearly all the explosions of stored explosives on record were exclusively due to the decomposition of the ingredients forming the blasting substance. The precautions to be used to prevent explosions caused by fire and percussions are the same that are taken in transportation and already discussed, but it is necessary to have the nitroglycerine products and the detonators stored in separate rooms.

In order to have the smallest possible damage in case of an explosion, it is necessary to locate the storehouse for explosives remote from any dwelling or village; to build it of light scantlings instead of heavy masonry, so as to oppose the least resistance to the gases, and for the same purpose it will be convenient

to surround and even cover the building with very loose earth or sand. According to the indicated principles, the engineer in charge of the work will prescribe special rules tending to insure the safety of men and property, and see that they are strictly observed.

CHAPTER VII.

ROCK EXCAVATION BY BLASTING; FUSES, FIRING, AND BLASTING.

Fuses.—When gunpowder is used as the explosive for excavating rock it is usually ignited by the Blickford match. This match, or fuse as it is more commonly called, consists of a small rope of yarn or cotton having as a core a small continuous thread of fine gunpowder. To protect the outside of the fuse from moisture it is coated with tar or some other impervious substance. These fuses are so well made that they burn very uniformly at the rate of about 1 ft. in 20 seconds; hence the moment of explosion can be pretty accurately fixed beforehand by cutting the fuse to the proper length. Blickford matches, especially when coated with tar, have the defect of burning with a bad odor, and this is very objectionable when the work is being done in closed spaces, as in a tunnel. Other fuses have been invented to do away with this trouble, and those of Rizha and Franzl are the best known of these. The former has many advantages, but it burns too rapidly, about 3 ft. per second, and is expensive; the latter consists of a small hollow rope filled with dynamite and is dangerous.

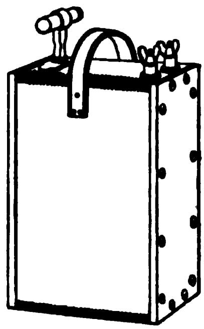


FIG. 80*b*.

It has already been remarked that dynamite does not explode by ignition, but by percussion; consequently the Blickford match alone cannot be used with dynamite. It can, however, be used to ignite and explode a cartridge which will in turn explode the dynamite. These cartridges consist of small copper cylinders containing fulminate of mercury, and are attached to the end

of the fuse which is inserted in the dynamite. The firing of explosives by means of the Blickford match is very seldom employed at present in the excavation of rock for public work. Blasts are usually fired by electricity, which is considered preferable, because several blasts can be fired simultaneously, and because

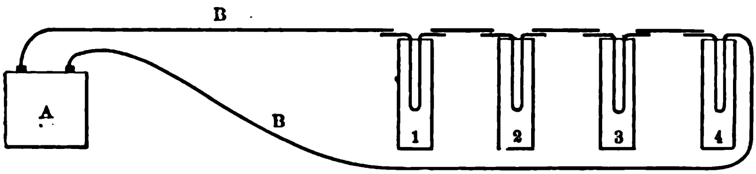


Fig. 31.

the current is turned on at a great distance, thus affording greater safety to the workmen.

The method of electric firing generally employed in America is known as the connecting-series method and consists in firing several holes simultaneously. The arrangement and connection of the wires are shown by the diagram Fig. 31. Before referring to this diagram, however, it is necessary to state that each hole charged with dynamite is provided with a detonator. This consists of a capsule containing fulminate of mercury. Two wires enter this capsule from the upper end and are connected at their bottoms by a very fine platinum wire. When an electric current is passed through the two wires, the fine wire which connects them offers such resistance to the current that it becomes red-hot and ignites and explodes the fulminate. Fig. 32 is a vertical section of a detonator of the character described. In blasting one of these detonators is placed in the middle stick of dynamite in each hole. Referring now to Fig. 31, the numerals 1, 2, 3, and 4 represent as many detonators in separate holes. The wires of these detonators are connected as indicated by splicing to them

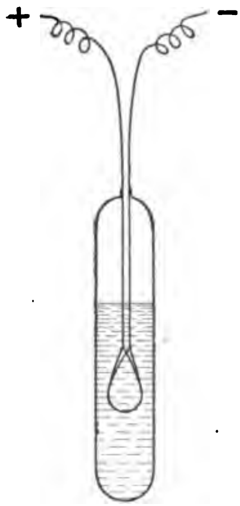


Fig. 32.

lengths of wire reaching from hole to hole, and finally the first wire of hole 1 and the last wire of hole 4 are connected to the firing-wires leading to the blasting-machine *A*. In connecting the various wires they should be scraped free of insulation and twisted together in close contact, and then the burr-joint should be wound with tape insulation. Failure to wind the joints with insulation causes trouble very often, because the burr-wire comes in contact with the earth, which draws the current from the wires. The dimension of the wires connecting the detonators from hole to hole should be equal to that of the detonator wires, while the wires leading to the blasting-machine should be at least twice the diameter of the detonator wires.

The blasting-machine illustrated in Fig. 30 consists of a wooden box enclosing a device fitted to revolve an armature wound to a very high resistance. The rapid revolution of the armature by pulling up the operating-bar generates an electric current of high electromotive power, which, at the moment of its maximum intensity, is sent out to the outside circuit in which are the detonators, the explosion of which is instantly accomplished. These machines are operated by a very easy and simple motion, which works smoothly and without any strain upon the parts. After being pulled up to fire, the operating-bar will fall back into its place of its own weight and is ready to be used again. On account of its special construction, in which the power is obtained by pulling up the bar, this blasting-machine is commonly called the pull-up machine. It is built in different sizes, the smaller with a firing capacity of from 20 to 30 holes, and the larger with a firing capacity of from 75 to 100 holes. The operation of firing is as follows: The operator turns down the two-hinged iron plates at the bottom of the box, and stands with his feet on them to hold the machine down; he then pulls the bar up with both hands with one continuous rapid stroke, and the blast is fired. The quicker the bar is pulled up the more current the machine will generate.

Tamping.—After a blasting-charge is placed in the hole it is covered by tamping, which is a material placed there to prevent the gases of explosion from escaping into the air. Tamping is

absolutely necessary with gunpowder, but it can be omitted when the explosive substance is a nitroglycerine compound. Gunpowder explodes slowly, and if the gases find an easy exit they escape without shattering the rock much, if at all; hence the necessity of closing all exit. This is done by filling the hole above the charge with damp clay which is well rammed into place by means of a wooden tool called a tamping-rod, illustrated by Fig. 33. As will be seen, this tool consists of a small wooden cylinder attached to a handle of the same material, the cylinder being provided with a groove in one side for the fuse-wires. No iron tool should be used in tamping because of the danger of striking a spark from the rock by a chance blow and thus prematurely exploding the blast. To protect the powder from being wetted by the clay a layer of paper, felt, dry cotton, or other substance is placed over the charge before inserting the clay. With dynamite the explosion is so sudden that the gases have no time to escape, and tamping is consequently not required. It is, however, commonly used, but without being rammed into place.

Tamping Rod
FIG. 33.

Firing.—The operation of firing the blasts should be entrusted only to the foreman of blasters or to some very careful workman. The following is the mode of procedure usually followed in firing: After all the holes have been connected with the leading wires of the blasting-machine a danger-signal is given by blowing a whistle or posting men with red flags around the danger-zone. Upon this signal all men leave the vicinity of the blast, and outsiders are prevented from approaching. All persons being out of danger, the foreman orders the blast to be fired. Upon this order, and not until then, the leading wires are attached to the blasting-machine, and the machine is operated as previously described. As soon as the blast is fired the men return to the work, and traffic is resumed in the vicinity. It is usually found convenient to fire the blasts at 12 o'clock or at evening, when the men are quitting work. If fired at other times, the time of firing is so much

lost from the men's working time, and the greater the number of men the greater this loss is. In case of a misfire the leading wires are detached from the blasting-machine and an inspection is made to locate the cause. This is usually found to be the grounding of the current because of defective insulation; this defect being repaired by insulating-tape, the wires are again connected up and the undischarged hole is exploded. Every care should be taken to see that the wires are in proper shape beforehand, however, as it is a trouble and waste of time to search out defects and repair them afterwards, especially in city work, where protecting mattresses and timbers have to be removed to allow the examination.

Blasting.—The cost of a cubic unit of rock excavation by blasting depends chiefly upon the amount of work and the quantity of material consumed. The work consists in drilling the holes, and the material is the quantity of explosive; both of these items, viz., the depth and frequency of the holes and the quantity of explosive employed, should be fixed by the engineer after a careful examination and series of experiments on the rock being worked. The writer has noticed that in the excavation of rock in this country no particular attention is usually given to these important features of the work. In every excavation it should be the duty of the engineer to fix the depth of the holes, their distance apart, and the amount of explosive to be used; and in order to do this he must have a knowledge of the phenomena of explosion.

When explosives are ignited a sudden development of gases results which produces instantly a violent increase of pressure, usually accompanied by a loud report. The energy of the explosion is exerted in all directions in the form of a sphere having its center at the point of explosion, and the waves of energy lose their force as the distance from this central point increases. The energy of the explosion at any point in the sphere of energy is, therefore, inversely proportional to the distance of this point from the center of explosion. Up to a certain distance the energy is great enough to shatter the rock and throw it violently

upward; up to a further distance the energy is great enough to break the rock, but not great enough to throw it from its bed, and from this last point to the limit of explosion only a shock is felt which decreases in severity as the outer limits are approached. There are, therefore, three concentric spheres of energy or force within the blasting sphere.

When the surface of the ground intercepts either the second or the third sphere the gases of explosion remain in the ground, but when it intercepts the first sphere the explosion detaches a cone-shaped mass of materials which are thrown into the air. This cone-shaped pit is called the blasting-cone. The base of this cone is the ground-surface, and its apex is the point of explosion; the smallest distance between the apex and the base is the line of least resistance. To secure the most effective blast the ground-surface should be tangent to the first sphere of energy, as then the rock will be thoroughly shattered but not thrown upward. When a large quantity of rock is thrown high into the air it means that a large quantity of gas has been wasted which should have been utilized in shattering the rock.

In blasting the quantity of the mass detached from the natural bed can be assumed as equal to the volume of the blasting-cone and is consequently given by

$$V = 1.05h^3n^2,$$

in which n is the inclination of the generatrices of the cone in respect to the axis, and h is the smallest distance between the point of explosion or apex of the blasting-cone and the ground-surface, or the line of least resistance. When, as usual, $n = 1$ the volume of the blasted material is given by

$$V = 1.05h^3,$$

and consequently the volume of the blasted rock is proportional to the cube of the line of least resistance, or, what is the same, to the cube of the depth of the holes..

When the rock to be blasted, instead of having only one surface to which the hole is perpendicular, has two surfaces at

right angles to each other, with the hole a continuation of one of the surfaces, the volume of the blast will be only one-half the blasting-cone and the detached mass will be

$$V=0.52h^3.$$

When the hole is drilled at the intersection of these surfaces only one-fourth the volume of the blasting-cone will be detached and the mass of detached rock will be

$$V=0.26h^3.$$

From these facts and from the experiments made on a cube and reported in all the text-books on blasting which showed that the efficiency of blasting increases with the number of free surfaces of attack, it can be deduced that the efficiency of blasting is directly proportional to the free surface of the rock attacked.

Knowing the quantity of rock detached at each blast, which has been observed to be proportional to the depth of the holes, the distance apart of the holes is readily determined to be equal to the depth of the holes. From the experiments of Mr. Höfer it is, however, known that the quantity of rock detached by mines or groups of holes fired simultaneously is double that detached by the same number of holes exploded in succession. This is a fact of great importance to engineers and constructors. While the distance apart of the holes should be equal to the depth of the holes in isolated firing, it may be from $1\frac{1}{2}$ to 2 times this depth for simultaneous firing. The most expensive item in the excavation of rock is the drilling of the holes for the blasts. Since the cost of drilling in the same material is constant per unit of length of hole, while the quantity of rock detached increases with the cube of the depth of the holes, if the greatest efficiency of blasting is to be had it is necessary to have deep holes. The deeper the holes the smaller will be the required number of feet drilled per unit of volume excavated. The most convenient depth of hole for practical work is from 8 to 12 ft.,

and usually the depth of hole should be about 10 ft. When, therefore, the depth to be excavated is great it should be divided into benches 10 or 12 ft. deep. Once the depth of the holes is determined it is a simple matter to locate their distance apart, since this should be equal to the depth of hole as a minimum, and not, as many contractors assume it, from 2 to 3 ft. apart.

The preceding discussion applies to homogeneous rocks, but these are seldom met with in excavation. The rock is usually stratified, and even when it is not its solidity and strength are not uniform. As a rule, any rock is more resistant to disruption in a direction perpendicular to its quarry-bed than in a direction parallel to it; consequently in blasting the waves of energy find greater resistance in one direction than in the other, and the rock will break unsymmetrically with respect to the axis. Hence, instead of a sphere of action as described above, we have an ellipsoid with the greater axis parallel to the direction of the strata, or the quarry-bed of the rock. This ellipsoid is seldom of regular form, since many circumstances, such as voids, fissures, veins of other materials, tried to make it irregular. That the waves of force spread in the form of an ellipsoid may also be deduced from the fact that the center of explosion is a line and not a point. If there were no other controlling considerations, it might be assumed as a practical rule to follow in work that the longer the axis of the charge the greater would be the ellipsoid of energy, but other considerations make it necessary to fix the charge according to more scientific principles.

In speaking of explosives it was remarked that the force of the gases of explosion varies in the same ratio as the weight of the explosive. From the above discussion it has been deduced that in blasting, other conditions being equal, the volume of detached rock is proportional to the line of least resistance, or to the cube of the depth of the hole. Therefore to produce the greatest effect the charge should increase with the cube of the depth of the hole. In practical work, however, this quantity should be multiplied by a certain coefficient, depending upon the force of the gases of explosion and the nature of the rock blasted.

According to G. G. André, the quantity Q of the explosive can be represented by the formula

$$Q = cv^3,$$

in which c is the coefficient and v is the length of the line of least resistance. The quantity Q is expressed in pounds, and the distance v in feet. The coefficient c is fixed according to experiment, and generally varies between 0.3 and 0.45 for gunpowder, and between 0.06 and 0.09 for dynamite and other nitroglycerine compounds. The engineer should not only fix the coefficient c after a series of experiments upon the rock being blasted, but he should instruct the blasters as to the different charges to be used under the various conditions of work. Thus, for instance, the same rock may be attacked in a direction perpendicular, parallel, or inclined to the strata, and in each of these cases a different charge should be used. The charge should also vary with the free surface of the blast. In blasting the first holes in driving the heading of a tunnel or the bottom of a shaft, they should be charged with more explosive than is used in any of the succeeding rounds of holes, since they have to detach a mass of rock bound in on all sides but one, while for the other rounds the hole already blasted forms free surfaces for the action of the blast. For the same reason it is usual to employ a more powerful explosive for these first holes.

It is often observed in excavating rock by blasting that, with holes of the same depth containing the same amount of explosive in the same rock, the effect will be very small in one case and much greater in another case. Owing to this fact, accidents often happen for which the blaster is innocent, but for which he is nevertheless frequently blamed and punished by law. Experiments made recently by Messrs. Roux and Sarrau give a scientific explanation of this phenomenon. These gentlemen claim that all explosive substances can explode in two ways: the one by means of heat they call *explosion;* the other by means of heat under great pressure they term *detonation.* In explosion the development of

the gases produced by the heat of combustion is relatively slow, it taking some time for the process to reach all portions of the charge. This time is infinitesimally small, of course, but it is appreciable. In detonation the explosion of every part of the charge is simultaneous and instantaneous. The effects produced by explosion and by detonation differ; in explosion the effect is to raise up and force down the surrounding material, and in detonation the effect is to crush this material. According to Messrs. Roux and Sarrau, gunpowder, which usually explodes, will also detonate when ignited by means of nitroglycerine or fulminate of mercury, and then the energy of the blast is much greater than the sum of the energy of the two materials exploded separately. The detonation of dynamite is obtained by means of capsules of fulminate of mercury tightly pressed into the dynamite. If the capsules are not strongly pressed into the dynamite, only a portion of it will detonate, while the other portion explodes. Messrs. Roux and Sarrau experimented on bombs of equal dimensions, and they found that it required only 4 grams of dynamite to break them when detonated, while it required 16 grams to break them when exploded.

A comparison of the relative energy of explosion and detonation of different substances is given in the following table, in which the energy of gunpowder is taken as unity:

Explosive.	Explosion.	Detonation.
Fulminate of mercury	...	9.28
Gunpowder	1	4.34
Nitroglycerine	4.8	10.13
Guncotton	3	6.4

The great advantage to be secured by obtaining full detonation of dynamite instead of part detonation and part explosion can readily be seen from this table. If all the dynamite could in blasting be detonated, only half the quantity now employed would be required. This would be a great advantage not only by reducing the cost of explosives, but by cutting in half the

amounts handled and thus reducing the chance of accidental explosion.

In conducting blasting operations in city streets or in thickly settled districts it is the usual practice to cover the holes with a protecting mattress before firing them. Such mattresses are usually made of logs about 1 ft. in diameter loosely chained together into a mattress-like bunch. In New York City each mattress usually consists of ten logs, and enough mattresses are used to cover the full area of the blasting-cone. Over these logs is placed a heavy netting made of $1\frac{1}{4}$- to $1\frac{1}{2}$-in. manila rope, or else a sheet of tin, usually a section of discarded tin roofing. Logs and rope nets are preferable to logs and tin sheets. The logs should be loosely tied together so that they give an elastic mattress to absorb the force of the explosion; if fastened rigidly together they will break and splinter. The operation of these mattresses is as follows: They rise into the air from the force of the blast, but confine the flying stones underneath and immediately drop back to near their original position because of their great weight.

CHAPTER VIII.

EARTH EXCAVATION: HAND-TOOLS; MACHINE EXCAVATION

HAND-TOOLS.

Shovels.—The simplest and perhaps the oldest tool employed in the excavation of earth is the shovel. This tool as shown in Fig. 34 consists of a wooden handle with a flattened iron or steel scoop or blade at one end. Shovels are made of different shapes for different materials, and they also vary in form with the usage of different countries. For excavating loose earths like quicksand and mud a blunt-pointed shovel is employed, while for excavating harder soils a sharp-pointed shovel is employed. Another difference is the length of the handle, which is sometimes long and sometimes short. In Continental Europe the long-handled shovel is generally employed, while in America it is more customary to use shovels with short handles. The writer thinks that this American practice has little more than prejudice to recommend it. The shovel is a lever whose fulcrum is where the workman grasps the handle with his left hand and to which the power is applied at the upper extremity of the handle. With a long-handled shovel, therefore, the lever-arm is longer and the power employed smaller, and consequently the amount of work performed by the laborer is greater than if he use a shovel with a short handle. Another advantage of the long-handled shovel

FIG. 34.

is that the laborer works in an upright position, and his endurance will be greater than if compelled to work bent over with a short-handled shovel. It is this line of reasoning that has led European engineers and contractors to favor the long-handled shovel. The author endeavored to investigate the reasons for the preference of American engineers and contractors for the short-handled shovel, but, with the exception that it was more handy and easy to transport, no plausible reason could be discovered. A member of one of the largest firms selling contractor's tools in America, in evident surprise that such a question should be asked, said, "Write on my authority that the long-handled shovel is the lazy man's tool," but he gives no reasons beyond this bold statement. Now since the laborer is to the contractor and engineer simply a working machine, utilized just for the amount of work it will perform in a day, it is necessary to obtain from this human machine the greatest possible amount of work, and this is accomplished only when it is allowed to work under the most favorable conditions. For this reason it would seem that the long-handled shovel should be preferred to the short-handled one. In fact, while in this country contractors consider it a fair day's work for a man to load from 7 to 8 cu. yds. into a cart, European engineers calculate 15 cu. m. as the average day's work of a man using the long-handled shovel. This difference of work obtained by the two different tools is so great as to command the greatest consideration.


FIG. 35.

Spade.—When the soil although loose yet offers some resistance to being removed from its natural bed a stronger tool than a shovel is employed. This is the spade, the construction of which is shown by Fig. 35. The blade is nearly flat and is made of heavy steel plate reinforced at the top edge. The handle is of wood with a cross-grip at the top. In operation the spade is pressed into the ground with the foot by thrusting against the reinforced edge. In this country the spade

is seldom used for general excavation, preference being given to a strong shovel with a sharp point and a reinforced top edge. The use of this shovel makes it unnecessary for the laborer to change from spade to shovel, thus losing time, or to handle soft material with a narrow-bladed spade. The efficiency of work with the spade varies with the character of the material, but with average material from 14 to 18 cu. yds. per day can be handled. At wages of $1.00 per day this makes the cost of simply removing 1 cu. yd. from its natural bed from 5½ to 7 cents.

Pick.—In soils which require a stronger tool than a spade a pick is employed. This tool with its wooden handle and long double-pointed head is familiar to every one and needs no description. In some cases both points are sharpened with a square taper, but often one point is chisel-edged either parallel to or perpendicular to the axis of the handle. In operation the sharp point of the tool is struck into the ground, and the handle is used as a lever to pry out a piece of earth. The chisel edge according to its direction is used like an axe or like a mattock or hoe. The efficiency of the work done with a pick varies with the character and conditions of the soil. It is generally deemed to be from twice to three times that of the shovel, and consequently the cost of removing a cubic yard of earth by means of the pick varies from 3 to 6 cents per cubic yard.

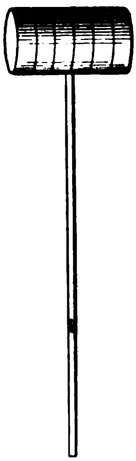


FIG. 36.

Sledge-hammer and Wedges.—Other tools which are sometimes used for excavating earth are sledge-hammers and wedges The sledge-hammers employed for this purpose may be of the same shape, weight, and dimensions as those used in the excavation of rock, but as in loose soils wooden wedges are used, the sledge can be made of a piece of heavy wood, usually cylindrical in form, which is bound with bands or hoops of iron and provided with a long handle, as shown by Fig. 36. The wedges are made of wood and are much larger than those used in the excavation of rock; they are from 18 ins. to 2 ft. long and from 8 to 12 ins.

thick on top. The sledge and wedges are particularly suitable for breaking down steep banks or faces of earth. The mode of procedure is to drive the wedges in a row parallel to the edge of the bank and a little back from it, and drive them until a seam is opened and a slice of the bank face breaks off. The higher the bank the greater is the efficiency of the method. Another method of removing banks by wedges is first to cut vertical channels or grooves at intervals in the face so as to leave buttresses of earth between them. The grooves are made about 1 ft. wide, and the buttresses left are 4 or 5 ft. wide and the same depth as the channels, or about 3 ft. When the whole face of the bank has been slotted in the manner described the buttresses are undermined by cutting a horizontal slot through them close to the floor of the excavation. This leaves the buttresses suspended and attached to the bank on only one side. They are then detached by means of wedges in a manner similar to that already described.

Blasting.—In open country away from habitations it is often convenient to use blasts for such work as breaking down a knoll of earth. A charge of several pounds of dynamite of about 30 per cent nitroglycerine is inserted in the ground and fired. The explosion loosens and breaks up the earth, so that it can be handled by shovels.

Hydraulic Excavation.—A method of excavation which is very cheap and which can be employed in some cases where water under pressure is available is to break down the soil by a powerful hose-stream and wash it away through wooden flumes discharging at some suitable point. This method of excavation has been much used on the Pacific coast in mining and for filling in railway trestles.

MACHINE EXCAVATION.

The magnitude of modern engineering works and the rapidity with which they are prosecuted make the pick and shovel too slow a tool for earth excavation, and they have been replaced by excavating-machines of various sorts which are capable of multiplying many fold the work done in a given time and at a

given cost. Earth excavation consists of two processes; the first is the displacement of the soil from its natural bed, and the second is the transferring of the displaced soil to vehicles for its removal. Excavating-machines must perform both these duties. Two general modes of procedure are followed in excavating earth; one is to remove the surface by scraping off thin layers, and the other is to remove a deep cut by taking successive layers from the face of a vertical bank. By the first method the excavating-machine used is in constant motion, and by the second method the machine does very little traveling. To the first class of machines belong the plow, the scraper, and the New Era grader, and to the second belong various forms of digging-machines. The first class of machines is operated by horse-power, and the second class by steam-power. For sake of convenience the various forms of excavating-machines on the market are classified according to their manner of working in the following table:

Excavating-machines.	**Attacking the earth all along the surface.**			**Plow.**
				New Era grader.
	Attacking the earth in banks.	**Machines working continuously.**	**Machine stands on the bank to be excavated.**	**Down-digging land-dredge.**
			Machine stands on the plane of the excavation.	**Up-digging land-dredge.**
		Machines working intermittently.	**Standing on the plane of the excavation.**	**Steam-shovel.**
			Standing on top of the bank to be excavated.	**Grabbing-buckets.**

Plow.—The simplest machine for breaking the ground to destroy the cohesion of the soil is the ordinary plow employed for agricultural purposes. The essential parts of this implement are: a triangular-pointed iron or steel share for slicing the earth at the bottom of the furrow; a mold-board attached to the right side of the share and having a helicoidal surface to turn

over the earth cut from the furrow; a standard connecting the mold-board and share to the beam, and a beam provided with a clevis at the forward end and with handles at the rear end. Sometimes a cutter projecting downward from the beam forward of the share is employed for compact and tough soils. Plows of

FIG. 37.

various forms and dimensions are found on the market, and nearly every manufacturer lays claim to superiority because of some patented attachment or improvement. In size plows vary from those which can be hauled by two and four horses to those which

FIG. 38.

require from ten to twelve horses to pull them. In some forms of plows the beam and handles are of wood, as shown by Fig. 37, and in others, as shown by Figs. 38 and 39, the beams are of iron and the handles wholly or partly of iron. When iron beams are used they are generally curved so that the share and mold-board are connected directly without the necessity of a standard. Plows with metal beams are always preferable, as they are stronger and more durable, there being no wood to decay.

Plows are usually employed for breaking up the earth so that it can be removed by drag or wheeled scrapers, and when used in

this way they are very efficient tools for cutting down a large area in thin layers. The depth of furrow removed varies from 4 to 12 ins., and its width is about 1 ft. According to Trautwine a plow drawn by two horses and operated by two men will break up from 200 to 300 cu. yds. of strong heavy soil and from 400 to 600 cu. yds. of ordinary loam per day of ten hours. The daily running expenses are the wages of the men and the keep of the horses, and they may be estimated at $1.50 and 75 cts. each, respectively which gives a cost of 1 to $1\frac{1}{2}$ cents per cubic yard for heavy soil and of .5 to .7 cent per cubic yard for loam.

The form of plow shown by Fig. 39 is designed especially for breaking up turnpikes, macadam roads, and cemented walks.

FIG. 39.

It has a heavy iron beam, to which the point is secured by two strong steel plates. The point is made of tool-steel, and is removable for sharpening or renewal. There is no mold-board or cutter. The handles and clevis are similar to those of ordinary plows. These plows may be drawn by horses, but it is more common to operate them by cables from stationary engines, particularly where the work is breaking up macadam road or cemented gravel.

New Era Grader.—If we define an excavating-machine as one which both breaks up and loads the earth, then the plow does not belong among excavating-machines The only reason for not including it among hand-tools is that it is operated by horse-power. The New Era grader is a true excavating-machine,

however, as it both breaks up the soil and loads it into carts for transport. One of these machines is shown by Figs. 40 and 41. Fig. 40 shows the excavating mechanism and Fig. 41 shows the loading mechanism. The machine is made entirely of steel. The main frame is arched and trussed so as to give lightness combined with the greatest possible strength and the necessary flexibility to allow the machine to conform to the uneven surface of the ground without the frame straining, twisting, or springing out of shape. This main frame is mounted on a truck with two driving-wheels and two hind wheels. On the truck there is a platform where the operator stands, having in front the sprocket-wheels for regulating the carrier or elevator. On the left side of the main frame is attached the plow-beam, made of a steel I beam. Perpendicular to the plow-beam there is a standard to which are bolted the plowshare and mold-board, so that, properly speaking, this machine can be considered as a very powerful steel plow with the cutter partially bolted to the plowshare and the whole plow perfectly fixed to the frame. In order to give stability to the machine and counteract the great weight of the carrier, this powerful plow is placed at the outermost point of the main frame of the truck. As in any other plow, there is the mold-board which turns the furrow removed from the soil by the share; with the difference that the furrow, instead of falling back on the ground after it has been revolved, falls on the lower end of the carrier and travels along it. The carrier is really an inclined belt conveyor in which an endless belt is stretched between two revolving drums placed at the extremes of a frame and running on rollers placed on the upper side of the frame. When one of the extreme revolving drums is moved by any motive power the belt is compelled to turn, and consequently in traveling along the frame it will carry with itself any material which has been deposited upon it. The drum at the upper end of the ladder is usually moved by a suitable arrangement in connection with the hind axle of the truck.

When the machine is in movement the plow excavates the earth, which is deposited on the lower end of the belt, and traveling

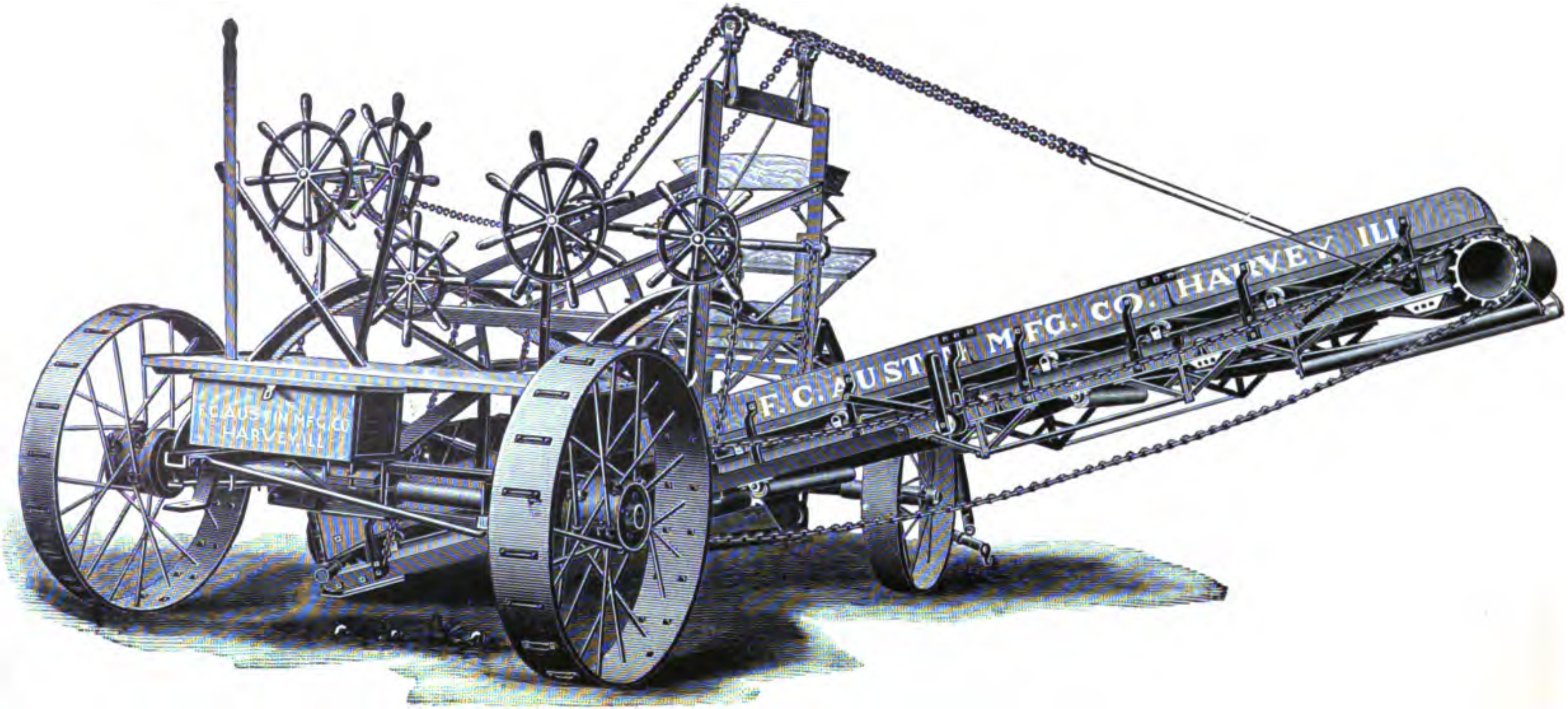


Fig. 40.

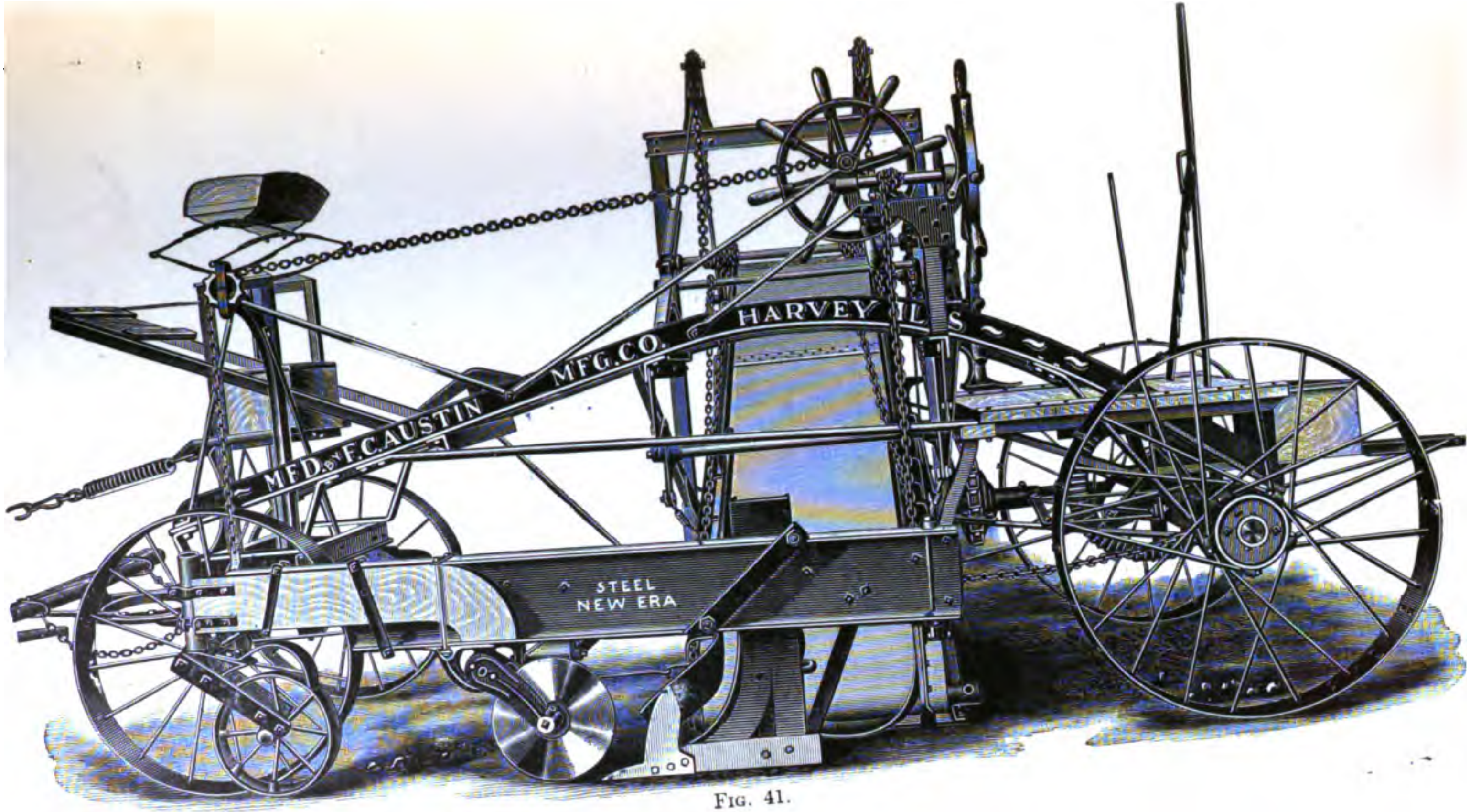


FIG. 41.

along it reaches the highest point and falls off. If now a wagon is traveling alongside of the machine, it will receive the discharged material and will thus be automatically loaded. Having enough wagons at hand so that as soon as one is loaded an empty one will takes it place, the result will be that the machine will not only excavate the ground, but also automatically load the excavated material.

The carrier is from 15 to 22 ft. long, and can be inclined at any angle by means of chains passing over sheaves supported by a steel frame attached to the main frame of the machine and wound around sprocket-wheels, which are regulated by the operator standing on the platform of the truck. The frame of the carrier is made of steel, thus giving lightness and strength at the same time. On each side of the upper part of the frame of the carrier there are two small boards which keep the excavated materials on the belt and prevent their falling sideways. The space between the mold-board of the plow and the lower end of the carrier is provided with a simple sand-lifting attachment, making it possible to load on to the carrier even sandy or light, dry soils.

The New Era grader is drawn by eight horses in front and four behind, hitched to a push-cart. It had been observed that when the motive power was applied only in front of the machine this was liable to easily stagger either on account of the inclination of the ground or of the small resistance met in the work. To avoid this and in order to have the machine always under control, it was found necessary to apply the motive power both in front and at the back of the machine. The four horses on the back are hitched abreast and driven by a man sitting on a push-cart, which is a simple two-wheel truck with a small seat. The shaft of the cart is very long, and by means of chains is strongly connected to the main frame of the machine. Fig. 42 illustrates the push-cart built by the Western Wheeled Scraper Company.

The New Era grader will work in any soil where an ordinary plow can be used, and over which teams and the machine can be driven. The plow on the machine will handle as much earth

as any four horses plow. Assuming that the teams, including the stopping, will travel at the rate of one and a half miles per hour, in ten hours a furrow 15 miles long, 1 ft. wide, and 6 ins. deep will be placed on the carrier, which is equivalent to 1460 cu. yds. of earth, and this is the theoretical efficiency of the machine. Such a quantity is not very far from what has been really obtained in practical work. As a rule it can be assumed that it is capable of placing in grade or embankment 1000 cu. yds. of earth, or loading from 500 to 600 wagons of 1½ cu. yds. capacity each in a ten-hour day, using but six teams and three men. The

FIG. 42.

efficiency of the New Era grader, however, depends chiefly upon the soil to be excavated; in light and sandy soils the work is very close to its theoretical capacity, while it can be assumed at only one-half of this through clay and one-third in hard-pan or gravel.

To load 1000 cu. yds. in ten hours a wagon must be at the side of the machine every thirty or fifty seconds. The length of the haul will govern the number of teams and wagons required. A team with a dumping-wagon by automatically opening the bottom will haul 90 ft., dump, and return for reloading in one minute. When the haul is not over 50 ft. four wagons will attend

the machine. For each additional 90 ft. one team must be added.

The cost of the daily work of the New Era grader is given by the wages of the men and the hiring of the horses, which is assumed to be $18; dividing this by the total amount of the work, the cost per unit of volume of the theoretical efficiency of the machine will be $\frac{18}{1400}=0.0128$. But in light and sandy soils, the actual work being 1000 cu. yds. per day, the cost per unit of volume will be $\frac{18}{1000}=0.018$; and in hard soils, like those encountered in the excavation of the Chicago Drainage Canal, in which the efficiency of the machine was 508 cu. yds., the cost per unit of volume is $\frac{18}{508}=0.035$.

New Era graders are extensively used in the excavation of canals, and are very valuable in constructing irrigation-ditches. They are also used with advantage in loading earth into wagons when the haul is from 600 to 3000 ft., and as a rule they give best results in the excavation of large quantities of earth extended over a large area, and when the depth of the excavation is not more than 10 ft.

The New Era grader just described and illustrated in Figs. 40 and 41 is built by the F. C. Austin Mfg. Co. of Harvey, Ill., while the cut of the push-cart has been taken from the Catalogue of the Western Wheeled Scraper Company of Aurora, Ill. This latter firm is building another similar machine built on the same principles as those of the New Era grader, but varying in the details, called the elevating grader, wagon-loader, and ditcher. These are the only two forms, to the knowledge of the writer, that are engaged in the manufacture of this kind of machines.

Automobile Steam Grader and Ditcher.—Lately a new machine has been introduced on the market by the Bunnell Machinery Company of Chicago, Ill., and is illustrated in Fig. 43. In order to lessen the operating expenses of the New Era grader, thus reducing the unit of cost of its work, made up, as has been seen, from

the large number of horses used as motive power, and from the employment of three men, two as drivers and one as operator, Mr. M. G. Bunnell undertook to substitute steam for the animal power, and the result was the automobile steam grader and ditcher. This consists of a fixed plow and a belt conveyor, like the New Era grader just described, with the exception that, instead of being mounted on an iron frame, they are supported by a tubular boiler, of the locomotive type, mounted on four

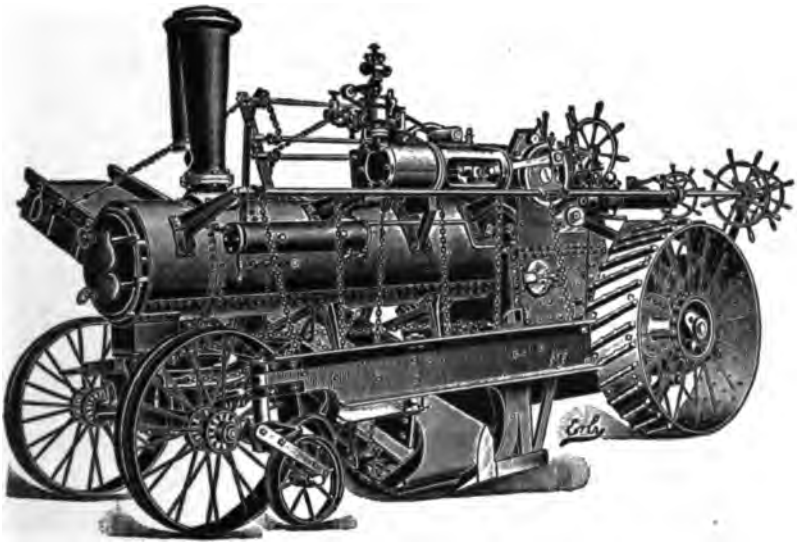


FIG. 43.

wheels. The two front wheels turn on an axle, which supports the boiler by means of a heavy forged bracket connected by a pin to a socket at the center of the axle. A chain on each side of the boiler leading to each of the front wheels and operated by the engineer directs the advance and turning of the machine. The rear end of the boiler with the fire-box, ash-pit, etc., is directly supported on the axle of the two large driving-wheels. The tires of these wheels are very wide, and are provided with transverse ribs to grip the ground. A small horizontal engine on top of the boiler engages a system of cog-wheels which cause the rear

wheels of the machine to revolve, thus propelling it. The same engine by means of beveled wheels and shafts imparts motion to the upper drum of the carrier, and consequently to the belt conveyor.

Steel brackets, fixed at each side of the boiler by means of chains, support both the plow and the conveyor. These chains are wound around shafts regulated by the engineer, who by simply turning a sprocket-wheel raises them and moves the machine as any ordinary road locomotive, or by lowering both the plow and the conveyor they engage the soil and the machine then works as a grader and ditcher. The plow is fixed to an I beam, having in front a small wheel so as to direct its course, and the I beam is suspended to the longitudinal shaft by means of two chains, and in the manner indicated in the illustration. The carrier is similar and works in the same way as the one described in the New Era grader. The machine is regulated by one engineer, who stands on a platform at the rear end of the boiler, having at his command all the wheels for the various movements of the machine.

The happy arrangement of the heavy boiler and mechanism at the center of the machine, with its working parts placed on each side of the boiler, makes the whole a very solid, compact, and easily handled machine, and the result is that very efficient work is obtained. Besides, such an arrangement prevents the staggering of the machine, a defect very common with the grader moved by animal power. For this reason, and also on account of the simplicity of direction, which is in the hands of one man, the theoretical work of the automobile grader is twice as much as that of the New Era grader, and experiments made at Waco, Texas, and Philadelphia fully confirm the statements of the manufacturers.

The cost of the automobile steam grader and ditcher is only $3000. Its operating expenses being calculated at $18 per day, the cost of the unit of volume of the work will be just half of that given for the New Era grader.

Speaking of the graders and ditchers, it is necessary to mention a grader which, although it cannot be considered as an

excavating-machine according to the definition given, is yet an essential part of any contractor's plant. This grader, or leveler, is chiefly used for finishing and leveling roads and to prepare them for the pavement; but in some cases it is also used in the excavation of small trenches and canals through very loose soils. Fig. 44 illustrates the Western steel reversible road-machine,

FIG. 44.

which is the latest grader placed on the market; similar machines, however, are built by the F. C. Austin Mfg. Co., Western Wheeled Scraper Company, and the Stuart Grader Company of Oberlin, Ohio.

The machine consists of a steel frame mounted on four wheels; the main frame is provided with a seat in front for the driver and a platform in the rear for the operator. The front wheels are small, so that the machine may turn on a small circle. Two iron posts fixed at the middle of the main frame support a beam, which is also connected with the frame above the axle of the front wheels. The beam supports a floating scraper-blade which is regulated by the operator by means of chains or levels. The scraper-blade turns on a disk and may be raised or lowered and

assume any position, so that it may excavate a ditch of any dimension and to a depth of $2\frac{1}{2}$ ft. The earth is turned over one side, and when the machine is working in the opposite direction the earth is turned over the other side, thus forming the ditches and embankments of small irrigating-canals. It is in this kind of work that the machine is very efficient and to which it is especially adapted. The axle of the hind wheels can be quickly extended on either side, so that the wheel on the delivering side of the machine is no obstruction to the discharge of the earth from the blade. The shape and construction of the scraper-blade, as well as the manner of regulating the machine in its work, form the claims of the various patents of this machine as manufactured by the different manufacturers.

The force required to operate a grader consists of five horses and two men, and the operating expenses can be assumed at $12 per day. The efficiency of the machine depends upon the soil and character of the work it performs. Thus, for instance, in leveling roads its theoretical efficiency can be considered at 35,000 sq. yds., and in excavating trenches through very light and sandy soil as 1500 cu. yds. It will be safe to assume the real working efficiency of the machine at only one-half these figures.

CHAPTER IX.

EARTH EXCAVATION: CONTINUOUS DIGGING-MACHINES.

EXCAVATING-MACHINES which also automatically discharge the excavated material into cars, thus performing the double purpose of excavating and loading machines, can be divided into two classes, viz., continuous excavators and intermittent excavators. With the exception of trenching-machines, several of which have been recently put on the market, no continuous excavators are used in America and England, but in Continental Europe they find great favor with both engineers and contractors. In England and America the preferred excavating-machine is the steam-shovel, or navvy.

Continuous excavators for land use are constructed on the same principle as the ladder dredge for marine use. They consist of two endless chains stretched between and passing around two revolving drums, and provided with scoops or buckets, which, being held against the ground-surface and given motion by revolving one of the drums, scrape up the soil and discharge it into suitable receptacles. The first continuous excavator was patented in 1859 by Mr. Chevreux, a Frenchman, and was used on the Suez Canal. Since then numerous other machines of this type have been designed and placed on the market. In some of these the ladder carrying the chain of buckets is placed transversely of the car and in others it is placed longitudinally, or parallel to the axis of the car. All of these excavators can, however, be classified either as up-digging or down-digging machines. The distinguishing features of these two forms of excavator are illustrated by Fig. 45. The down-digging machine is located on the surface being excavated, is a machine of large dimensions and

great power, and is used for deep excavations; the up-digging machine stands on the new surface formed by the excavation, is of

FIG. 45.

smaller dimensions and power, and is used either on shallow cuts or to prepare the work for down-digging.

Down-digging Machines.—To illustrate machines of the down-digging type the continuous excavator built by Henry Satre of Lyons, France, is shown in Fig. 46. This is one of the most perfect machines of the type, and has been extensively used in Europe, on the Panama Canal, and elsewhere. The excavating mechanism proper is located on a steel platform supported by a double truck running on tracks of ordinary gauge. To increase the stability of the machine while at work two other wheels are inserted on the excavation side, and for the same purpose a third rail is introduced, and the axles of the hind wheel of the front truck and that of the front wheels of the hind truck are made much longer in order to receive these supplementary wheels. The machine is self-propelling by means of an endless chain running from a sprocket-wheel on the crank-shaft of the engine to a sprocket-wheel on the front axle of the hind truck.

On the steel platform on the opposite side of the ladder is mounted a return-tubular steam-boiler, 11.24 ft. long and 5 ft. in diameter, having a total heating surface of 537 sq. ft. A double-cylinder reversible vertical engine of 55 H.P. capacity is used. This by means of an endless chain and sprocket-wheel moves the upper tumbler of the ladder fixed to a frame firmly secured to the plat-

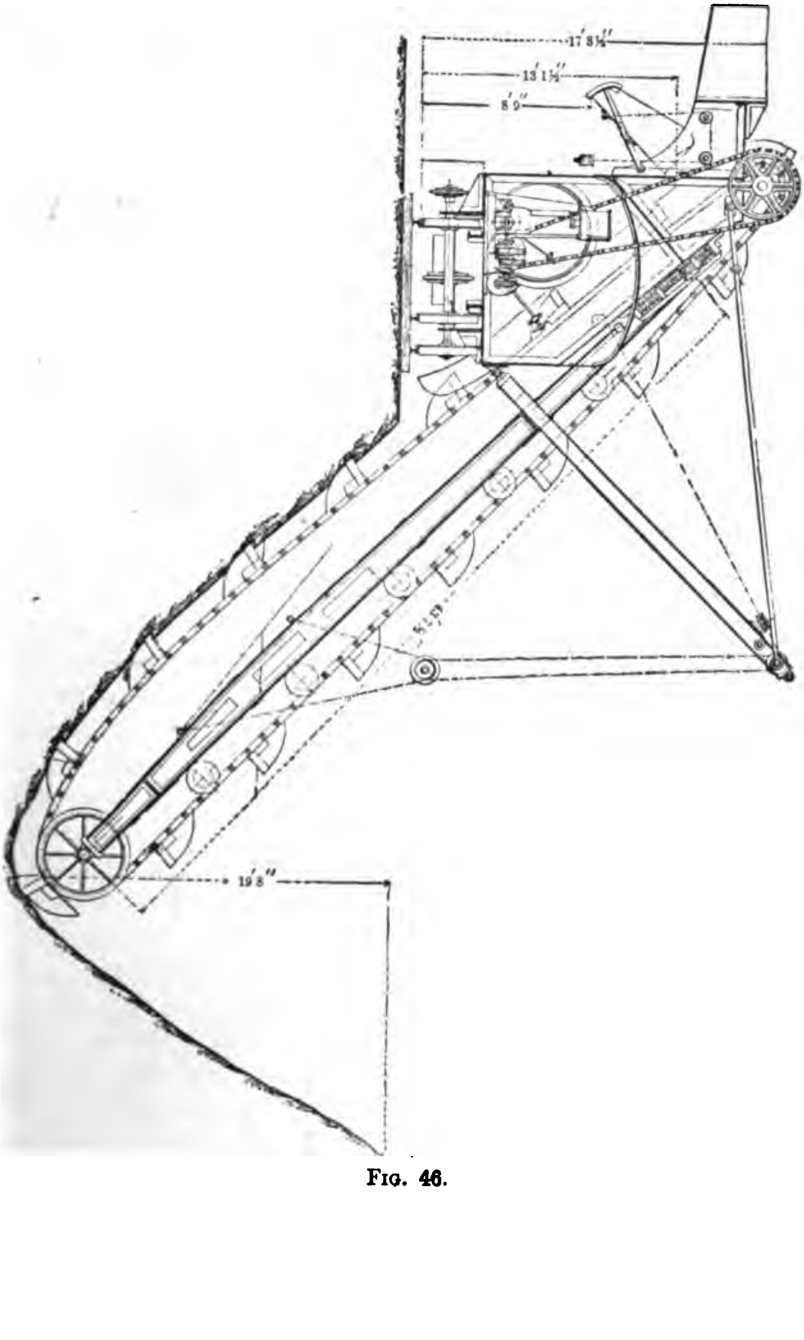


FIG. 46.

form of the car. The tumbler is composed of an axle with two hexagonal wheels, each side of the hexagon being such as to perfectly receive the links of the articulated chains carrying these buckets. The hexagonal wheels are placed 3 ft. apart, thus leaving a free space into which the buckets, in turning over, unload their contents into a hopper and through a chute to the cars.

The ladder is made of two trussed iron beams, 43.6 ft. long, braced together and provided with rollers on the upper side so as to facilitate the running of the chains. It is fixed to the frame of the tumbler and chute by means of two heavy turnbuckles, which permit regulating the tension of the chains carrying the buckets. To insure the stability of the machine a hollow box of 5 tons capacity is located on the opposite side of the ladder at the level of the tumbler. At the lower end of the ladder there are two flanged sheaves for guiding the chains. The ladder is hinged at its upper end and free at the lower, so that it may assume any angle, thus closely following the inclination of the slope of the ground to be excavated. The raising and lowering of the ladder is obtained by means of a chain regulated by a single reversible drum and a system of sheaves, the most important being the one placed on top of a framed jib. This jib consists of two I-beams 4 ft. apart and braced together at their upper and lower ends and near the center, thus leaving large spaces in order not to interfere with the ladder. The lower end of this jib is pivoted to the platform of the car, and the upper end is braced by means of iron rods to the frame carrying the driving-tumbler.

The buckets are of steel, of 7.76 cu. ft. capacity. They are constructed with a hemispherical face provided with a sharp cutting edge; their backs are flat and are attached to the links of the chains, the links being hung at the back of the buckets. When the ladder is lowered down in contact with the bank, the buckets, by gradually cutting a slice all the way up the bank, become filled and carry the material up to the driving-tumbler. When the links of the chains attached to the buckets turn over the tumbler the material will fall by gravity into the hopper and through a chute into the cars. Twenty buckets turn over the tumbler every

minute, so that the theoretical efficiency of this machine per ten-hour day will be $7.76\times20\times60\times10=93{,}120$ cu. ft. or 3450.45 cu. yds. Notwithstanding that the experiments made at Pantin, France, have given actual results very close to the theoretical efficiency of the machine, its real work depends upon many circumstances, the most important being the quality of the soil to be excavated and the manner in which the work is arranged. In the excavation of the Panama Canal 300 cars of 6 cu. yds. each is the average efficiency of the Satre excavator.

As a rule these continuous excavators give the best results in sand, soft clay, and dirt; and their efficiency also depends upon the arrangement of the work. They require in particular empty cars always at hand to receive the excavated materials. Since the buckets must continually attack a new surface, the machine has to be moved very often, and it is thus considered more convenient to place the machine alongside the trench to be excavated than at the front, since it will then have to travel the entire length of the trench before it returns to the first position, thus allowing all the time necessary for the arrangement of the tracks.

This machine works well to a vertical depth of 20 ft. It is operated by an engineer, a coalman, a fireman, three carmen, and a chainman, and its consumption of coal is 3 tons per day. Considering the wages of the engineer at $3 per day and those of the other men at $2 each, and the cost of coal at $4 per ton, the daily expenses of running this machine will be $27 or $0.008 per cu. yd. of the theoretical capacity and $0.015 of the actual capacity.

In the excavation for the improvement of river shores or canal slopes the continuous down-digging machine gives the best result. Its employment is also very convenient in the excavation of wide trenches greatly extending in length, and where the excavated materials are deposited on wash-banks away from the line of the work. But it is not at its best in working trenches where the excavated material has been used in the embankments for the construction of the road-bed, except in the case that the excavated earths can be hauled directly from the top of the trench

to the embankment on specially built temporary roads and not along the newly constructed road-bed.

Down-digging machines of different capacity are on the market; they vary from very light to heavy models. In selecting one of these machines, however, it will be better to choose a model of medium size; a too light machine may be easily overturned, while one that is too heavy is difficult to transport and liable to fall down the bank which it undermines. It must be remembered that the down-digging machine, Mr. W. P. Williams says, rests on the edge of the terrace and the slope, inclined at an angle of two to one, is not flat enough to prevent a sliding tendency of the bank caused by a 50-ton weight and a vibratory movement from the contact of the bucket with the bank. But, on the other hand, Mr. A. W. Robinson says it is claimed that, as they stand on top of the bank instead of in the bottom of the pit, they have the double advantage of being independent of seepage-water, and of requiring less locomotive power to haul away the loaded trains.

Up-digging Machine.—It has been observed in down-digging machines that the tendency of the buckets to retain their contents is inversely proportioned to the slope of the bank. The buckets are traveling in a position very near the vertical when the slope of the bank is very small, while they are traveling nearly horizontally when the slope is very inclined; consequently the buckets are in the most favorable position and perform more efficient work when the bank upon which the machine is working has small inclination and when it is most liable to cave in under the great weight and strain of the machine. To avoid such an accident Messrs. Jacquelin & Chevre have devised a machine in which the buckets travel in a vertical position, assuming the inclined one when passing over a tumbler where they discharge their content into a hopper. Fig. 47 represents the Jacquelin & Chevre continuous excavator as modified by Mr. Charles Bourdon and employed in the excavation of the Panama Canal.

The machine is mounted on a steel turntable resting on a strongly framed iron-and-steel platform car supported on a four-

wheeled truck which runs on tracks of ordinary gauge. A tubular boiler is placed on the turntable at the rear end of the car, its axis being transversally to the longitudinal axis of the truck. It is arranged in this way in order to be in equilibrium with the

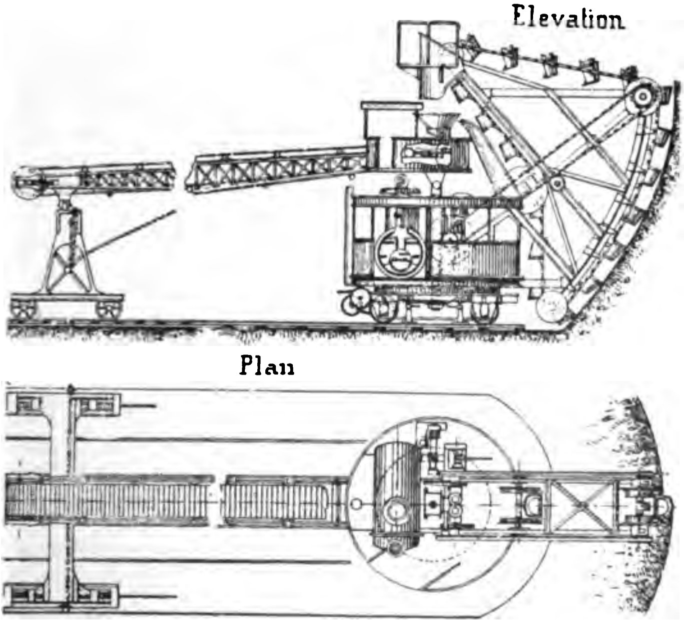


FIG. 47.

ladder and buckets, which are located at the front end of the machine. A vertical engine operating the machine is placed at the center of the turntable. The engine by means of sprocket-wheels and chains causes the rotation of the upper tumbler of the ladder, thus imparting the motive power to the excavating part of the machine. The engine causes also the rotation of the turntable around its axis in order that the ladder may turn on a radius and be brought continuously in front of new surfaces of the bank to be excavated. In many cases the engine commands also another drum guiding the belt conveyor upon which the

material from the hopper goes to the rear end of the machine and is dumped into the cars. The machine is not self-propelling, its movement ahead being obtained by means of a rope which is wound around the winch-head of the engine and passes over a sheave fixed to a post strongly located in the ground in front of the machine.

The ladder is made up of a triangular frame fixed to the turn-table by means of iron rods, and it carries four drums. Each section of the ladder is composed of two iron beams braced together and having an open space in the center in order not to interfere with the travel of the buckets. Of the four drums carried by the ladder only one is operated by the engine, the others being simply used to guide the chains carrying the buckets. The drums are composed of an axle and two grooved sheaves of polygonal form, the sides of the polygon being made in such a way as to give full support to every link of the chain when they pass over.

The buckets, instead of being fixed to the links of the chains as in down-digging machines, are simply suspended to a horizontal steel axis. The bottom of the buckets is provided with steel spurs which slide upon the flanges of the beams on the excavating side of the ladder, thus giving a stronger support to the buckets while they are under the strain of tearing the earth from the bank. The capacity of the buckets is 2.24 cu. ft. The velocity of the chain is 0.984 ft. per second, 15 buckets passing over the tumbler every minute. The theoretical efficiency of this machine per ten hours is $2.24 \times 15 \times 60 \times 10 = 20{,}160$ cu. ft. or 746.66 cu. yds.

Up-digging machines can easily cut banks from 25 to 30 ft. high. They are very useful in the excavation of trenches for single-track railroads, in which all the cut at the front can be made on a single advance. Working at the center of the cut when the transportation is done by cars running on narrow-gauge tracks, a single-track line can be placed on each side of the machine. The excavated materials reaching the rear of the machine, traveling on a belt conveyor, fall either at the right or at the left, thus loading the cars, which on account of the two tracks may be always at hand. In such a condition the machine may work con-

tinuously; the only time lost will be in its advance, which, however, takes only a few minutes, and its actual will be very near its theoretical efficiency. But in calculating the capacity of this machine it will be convenient to assume it at two-thirds of its theoretical efficiency; in round numbers it will be 500 cu. yds. per ten hours' work.

The running expenses of the up-digging machine is calculated at $18 per day, and the cost of excavation of 1 cu. yd. of earth will be $0.024 based on its theoretical efficiency, and $0.032 based on its real work. The weight of the machine is thirty tons, and when working on newly excavated ground the tracks upon which it runs must be strongly timbered. Up-digging machines are exclusively used by Continental contractors, especially in Germany, but do not find any favor amongst Americans and Englishmen.

The Austin-Trench Excavating-machine.—Built on the same principle as continuous excavators, there is a small machine for the excavation of narrow trenches, called the Austin trench-excavating machine and built by the Municipal Engineering and Contracting Company of Harvey, Ill. It was thus described in the *Engineering News* of Sept. 19, 1901:

The machine (Fig. 48) consists of a frame built up mainly of steel I beams and mounted on four broad-tired wheels. Over the front axle is a shaft to which is pivoted a frame about 20 ft. long, composed of two steel channels connected by cross-pieces. The shaft at the head of the machine, to which this frame is pivoted, and another shaft at the outer end of the frame are each fitted with two hexagonal sprocket-wheels carrying a pair of endless link-belt chains, built up of steel drop-forged links connected by cross-bars and flat blades or scrapers. Each cross-bar is fitted with two or three cutters of drop-forged steel, the cutters on the several bars being staggered so that the entire series of cutters will cover the whole width of the excavation. Alternate bars are also fitted with side cutters or reamers for trimming the sides of the trench so as to give a clearance for the cutter-frame. The blades behind the cutters form scoops to carry up the material removed by the cutters.

At the rear end of the machine are two vertical sliding bars, the lower ends of which are attached to the end of the cutter-frame. The bars are fitted with racks, gearing with pinions on a transverse shaft above the rear axle. This shaft is driven by gearing and the arrangement constitutes a "crowding" device for forcing the cutter-frame against the bottom of the trench, so that the greater part of the weight of the machine is carried by the breast of the cut.

FIG. 48.

The depth of the cut is regulated by raising or lowering the free end of the cutter-frame. The cutters travel up along the working breast, loosening the material which is carried up by the blades or scrapers. At the head of the machine this material is dumped upon two horizontal belt conveyors at right angles to the trench, which discharge the excavated material either into wagons for removal or upon the ground alongside the trench ready for the back-filling. The machine hauls itself along by means of a wire cable anchored about 300 ft. ahead. This cable is wound upon a drum which has at one end a ratchet driving-wheel. The pawl of this wheel is operated by a rod from an eccentric on the main shaft of the machine, and the throw is adjustable, so as to allow

of regulating the speed of advance or feed according to the depth of cut and the character of the material.

Power is derived from a 25-H.P. traction engine coupled ahead of the machine. The main shaft of the engine carries a sprocket-wheel connected by a link-belt driving-chain with a similar sprocket-wheel on the main shaft of the excavating-machine. From this latter shaft a link belt drives the shaft at the head of the cutter frame, while vertical link belts drive the bevel-gears from which the conveyors are operated. Two men are, required one to operate the traction engine, and the other to operate the excavator, stopping and starting the cutting mechanism, and regulating the speed as required. Other men attend to the hauling cable, the trench-sheeting, and the back-filling.

The Austin trench-excavating machine supplies a long-felt want in the engineering profession. To open a trench for pipes or sewers, when the work is done by hand, often requires the removal of much more material than is actually needed for the trench, owing to the necessity of having the trench wide enough for the men to handle their tools. In deep trenches, also, the work by hand labor is often increased by the necessity of working in stages, the material being handled two or three times before it reaches the surface. The Austin machine does the work cheaper and quicker than by hand. It has already been used on contract work with success in different kinds of soil. At Glencoe, Ill., about 6,000 ft. of trench have been excavated with this machine, the width of the trench being 2 ft. and the depth from 9 to 15 ft. The material was very hard stiff clay. The 2-ft. trench would be too narrow for excavation by hand, but just allows room for the pipe-layers to work, the pipe being kept up to within about 15 ft. of the machine. Behind the pipe-laying the back-filling was done by a horse and drag scraper, with two men; the scraper working across the trench and scraping the excavated material from the ridges into the trench. In this hard material the excavator dug about 50 ft. an hour, but in good earth free from boulders the progress may be as much as 100 ft. an hour. At Glencoe 590 ft. of trench 13 to 15 ft. deep were excavated in a working day of ten hours.

Small boulders can be handled, the cutters loosening the material

around them until they fall out and are carried up by the blades. For large boulders the cutter-frame can be raised and the stone removed by picks. The machine will work in any place where there are not too heavy rocks which the machine cannot handle. It will cut trenches 24 to 48 ins. wide and as deep as 20 ft.

Still another machine working on the same principle as the continuous excavators is the endless-chain excavating-machine, used in the excavation of the tunnel for the Central London Ry. It represents the only machine that has ever been employed in the excavation of tunnels through loose soils. The special construction of the ladder and the buckets travelling horizontally are due to the particular condition of the work this machine was intended to perform; but with a slight modification it could be easily made a very practical trench-excavating machine. It is also very interesting on account of being the first excavator run by electricity. The description and cut (Fig. 49) of this machine are taken from the *Engineering News*.

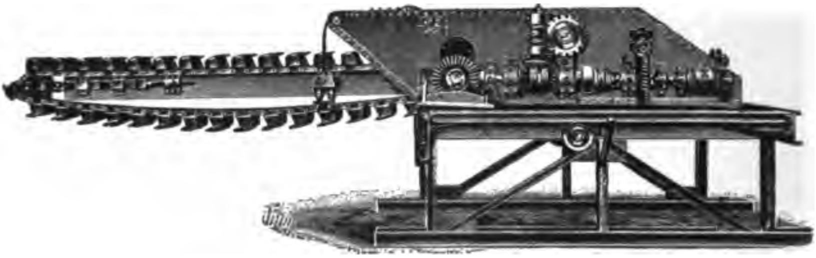


FIG. 49.

This excavating-machine consists of an under-carriage with wheels running on a 6 ft. 3 in. gauge track. This carriage has an opening beneath 5 ft. 8 ins. high and sufficiently wide to admit the usual 2 ft. gauge cars underneath it. The top of this carriage is strongly braced and carries a short king-post on which an upper carriage revolves. This upper carriage has sides of plate-iron, cross-braced and with a central casting revolving on the king-post; attached to the top of this carriage is an endless chain carrying excavating-buckets. The frame which carries this chain is 17 ft. long and is held up by two chains passing to a winding-drum in the upper part of the carriage.

The machine is driven electrically by a 100-ampere motor taking current at 200 volts. The current is supplied by a 20-H.P. engine and dynamo at the head-house. The motor is mounted on the back end of the carriage and drives a shaft parallel to the carriage by a two-thread worm and worm-wheel. This shaft also operates the revolving, the propelling, and the raising and lowering gear by suitable bevel pinions and wheels. The revolving-gear consists of a pair of friction-cones and bevel-wheels driving through a worm-gear, a chain-pulley with chains passing to the sides of the under-frame. The raising and lowering of the bucket-ladder is also performed by a pair of friction-cones and a worm-gear, and on the barrel of the latter the lifting-chains are wound. The traveling gear is worked from a pulley on the opposite end of the motor and belted to a pulley on a shaft over the king-post. From this latter shaft, by means again of friction-cones, another shaft leading down the king-post is operated, and drives, by a worm-gear, two spools placed on either side of the under-frame. From these spools wire ropes are led and anchored to the sides of the tunnel, and by them the machine is moved.

As the excavating-buckets are run at higher speeds than those used on dredges, especial care has to be given to the feed, and all levers and wheels for the control of the machine are within easy reach of the operator, who stands on a small platform on the left of the machine. The bucket-ladder is fitted with a screw extension device for tightening up the bucket-chain. The buckets are really scrapers and each has four or five teeth, placed alternately, chisel-shaped and fitting into recesses cast in the back of the buckets; but as one or two were broken, gun-metal has since been employed with better results.

While the machine is not as large or heavy as experience shows would be desirable, the only stoppages have been due to the breaking of buckets. As it is, the saving over hand labor is very considerable and an average advance of three 20-in. rings is made in ten hours with eight men at the face, including the machine operator.

CHAPTER X.

EARTH EXCAVATION: INTERMITTENT DIGGING-MACHINES.

LIKE continuous excavators, those which operate intermittently may be divided into two classes, those which excavate upward and those which excavate downward. Steam-shovels, or navvies as they are called in England, are up-digging machines and orange-peel and clam-shell excavators are down-digging machines. Each of these types of excavators will be discussed by itself.

Steam-shovels. — If we observe the movements of a man shoveling it will be seen that they are as follows: (1) The shovel is lowered; (2) the blade is thrust into the ground; (3) the filled shovel is raised; and (4) the shovel is swung around to discharge its load into the waiting wagon or car. All these movements are exactly reproduced by the steam-shovel. The shovel proper consists of a large bucket or dipper attached to a dipper-handle supported by a boom or jib which can slew around a full semi-circle or more. It is operated, through a system of chains and sheaves, by a three-drum reversible engine located on a car which also carries the steam-boiler and all other operating machinery. Steam-shovels are self-propelling and are operated by an engineman and a craneman. The movements of a steam-shovel in operation are as follows: (1) The dipper is lowered to the ground; (2) its edge is thrust into the bank; (3) the dipper is then raised so as to scrape or scoop out the bank until full; and (4) the dipper is swung around over the car and its contents discharged by unhitching the bottom, which swings open on a hinge. The lowering of the bucket is accomplished by loosening the hoisting-chain, which passes over the top of the boom and supports the pulley to which the dipper is attached. The second movement is obtained by

lengthening the dipper-handle; this is done by the craneman, who stands at the foot of the boom. By means of a foot-break he can arrest the dipper-handle in any position, thus having a point of support around which it may rotate. The raising of the dipper is accomplished by reversing the drum of the hoisting-chain; the bucket scraping the earth is filled with dirt. Then the craneman loses a little the foot-break, and withdraws the dipper-handle so as to disengage the bucket from the material. The slewing of the boom or jib is accomplished by a chain encased horizontally in a groove of a large wheel at the foot of the boom. In turning, the bucket reaches a position just above the car to be loaded; the craneman then pulls a rope commanding a latch at the bottom of the bucket, which is thus opened and the earth falls by gravity into the car below. The bottom of the bucket closes automatically when the dipper is brought back against the earth to be excavated.

According to Mr. Hermann, the first steam-shovel was designed and patented by Mr. Otis about 1840, but it was not until 1865 that the machine came into general use. It is now built by several manufacturers, whose machines vary in the design of various parts, but the principles of operation are essentially the same in them all. Only two models of steam-shovels will be illustrated here, the Barnhardt steam-shovel, built by the Marion Steam-shovel Company of Marion, Ohio, and the Dunbar-Ruston steam-navvy, built by Ruston Proctor & Co., Ltd., of Lincoln, England.

Barnhardt Shovel.—The Barnhardt steam-shovel, illustrated by Fig. 50, is mounted on a platform car supported on two four-wheel trucks of the usual construction and ordinary gauge. The bolster and cross-ties of the car-frame are of white oak reinforced by steel channels. The sills are of steel channels and I beams, with wood filling, securely bolted together and riveted to heavy steel end plates. The car is provided with a draw-bar at each end allowing it to be coupled into freight trains and hauled at ordinary freight speed. To prevent the car from tipping under the great strain of the shovel, the base of the car is greatly in-

creased by means of two steel jack-braces attached one on each side of the front end of the car. The jacks being hinged are easily folded alongside of the car in passing obstructions when the whole machine is in movement.

Both the boiler and the engines are located on the platform of the car, the boiler being at the rear end, the engines near the center of the car; they are protected by timber side walls and corrugated iron roof. The size of the boiler and engines varies with the various models, but in the model G, here illustrated,

FIG. 50.

the boiler is of locomotive type, 54 ins. in diameter; the fire-box being 48 ins. long, 48 ins. wide, and 54 ins. high. It contains 70 flues 3 ins. in diameter, each 72 ins. long.

Two double-cylinder vertical engines are employed. The one used for hoisting has cylinders 10×12 ins., and the other, used for thrusting, has cylinders 7×8 ins. The drum-shaft rotates continuously in one direction. On it there is mounted a heavy steel gear, driven by steel pinion on the engine-shaft. Three friction-drums are also mounted on this shaft, the hoisting-drum in the center and the swinging-drums on the ends.

In front of the covered car there is a turntable with grooved flanges to encase the slewing-chain of the boom. The turntable is thoroughly braced and stayed in every direction by means

of steel plates, bars, and forgings, securely riveted together. At the center of the turntable is fixed the foot of the boom, which may turn by turning in opposite directions the two drums commanding the slewing-chain. The boom is an inclined oak beam reinforced by steel plates, bars, and forgings, with a slot in the center; its lower end is fixed to the turntable and its upper end is tied, by means of an iron rod with turnbuckle, to a pin inserted at the top of the A-frame structure. This consists of two racking-beams made up of heavy steel bars and forgings, with filling of white oak, surmounted by a cast-steel headpiece and in the shape of the letter A. The A frame is connected at the bottom with pedestals by means of heavy forged-steel hinges, extending through to the under side of the sills of the car, and it is also braced to the rear end of the car.

The boom commands the shovel, consisting of a large bucket and the dipper-handle. The latter is made up of a square oak beam reinforced by steel plates, bars, and forgings. Its lower side is provided with a rack engaging a system of cog-wheels which are, in the latest models, moved by a small engine mounted on the boom. Such an arrangement permits the lengthening and shortening of the handle, and by a break it may be arrested in any position, thus having an axis around which it rotates.

The bucket or dipper is of 2½ cu. yds. capacity. It is of plate-steel, with a semi-elliptical cross-section. Its cutting edge is armored with four heavy forged-steel teeth running to the bottom of the bucket. They are fastened by iron bars and bolted to the bucket with flat-headed bolts, so that they can be easily removed and changed when damaged. The bottom of the bucket or dipper is made of steel plate and is hinged at one side and kept closed by means of a spring-latch. The bucket is provided with two racks, one near the top, and is attached to a sheave suspended to the hoisting-chain; the other rack is placed near the bottom and is fixed to the handle.

This machine can excavate and load two buckets every minute, and consequently its theoretical efficiency is $5\times60\times100=3000$ cu. yds. On account of the difficulty of coordinating the work of

two or three operators and the loss of time in advancing the machine, clearing the tracks, waiting for the cars, and other obstacles which are met with in the excavation, it is safe to consider the real practical work of this machine not more than one-half of its technical capacity, and usually about one-third. The running expenses of this machine can be assumed at $24, divided into the following items: Two engineers at $3 each; one craneman and one fireman at $2; six carmen at $1.50; 1 ton of coal at $4; and $1 for oil, water, waste, etc. The cost of excavating 1 cu. yd. of earth with this machine will be 0.8 cent at full capacity, 1.6 cents at one-half capacity, and 2.4 cents at one-third capacity.

Dunbar & Ruston Navvy.—The steam-navvy used in England is much similar to the steam-shovel. Fig. 51 illustrates the Dun-

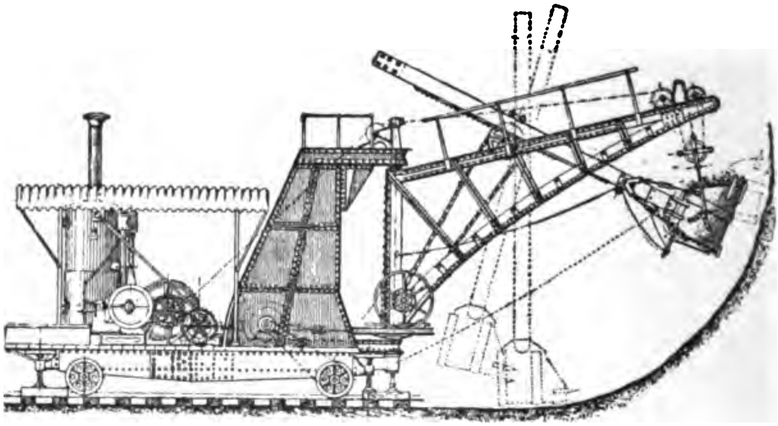


FIG. 51.

bar & Ruston steam-navvy as used in the excavation of the Panama Canal. It consists of a strong rectangular wrought-iron frame mounted on wheels, forming a substantial base to which all the parts are secured. At each corner of the frame is a strong jack-screw, and a fifth is placed immediately under the pivot of the jib on the front end of the frame. These take the entire weight when at work.

On the back end of the frame is located the engine beside

which the driver stands. The engine is of the ordinary vertical type, with a cross-tube boiler carrying usually 80 lbs. pressure, and has a pair of cylinders of 10 H.P. nominal. It runs up to 160 to 170 revolutions per minute under the control of a governor. On the crank-shaft is keyed a pinion, gearing into a spur-wheel four times its size on the main drum-shaft, from which all the other motions are transmitted.

At the front end rises a wrought-iron tower carrying the top pivot of a crane-jib, the lower pivot resting on girders fixed to the main frame. The tower is an oblique truncated pyramid, well extended at the base for bolting to the longitudinals of the main frame. It is formed of the plate sides, stiffened with T irons, and braced together with cross-plates and stays. Between the plates is an opening large enough for the driver to watch the motion of the bucket, even when the jib is straight ahead. The top of the pyramid is finished with a roof-plate extended forwards in front for taking the top pivot of the jib, and stiffened by a V-shaped girder like that for the bottom pivot; on this table are placed also the guide-pulleys for the main chain.

The jib may be said to be of twin construction, being composed of two sides which are united only at the post and at the outer end or point; between them, therefore, is a long slot in which swings an arm of adjustable length, depending from a fulcrum fixed on the upper member of the jib. At the base of the post is a circular platform, on which a man stands to regulate by means of a hand-wheel the "reach" or length of radius of the arm.

The bucket-arm is made of two oak planks bolted together at top and bottom so as to leave a long slot between them, through which passes the main chain. On the back edge of each plank is a rack, gearing with a pinion fixed on the fulcrum-shaft on the top of the jib. The same shaft also carries a swing-frame provided with four rollers, which press on iron bars or runners fixed along the front edge of the arm so as to hold it up close to the fulcrum while yet allowing it to be moved longitudinally by the racks and pinions for lengthening or shortening it; the movement is given by a pitch-chain wheel on the outer end of the fulcrum-

shaft, driven from a pinion on the hand-wheel shaft, which is under the control of the wheelman.

The bucket is made of steel plate; its mouth is semi-elliptical, and its cutting edge is protected by four strong picks or teeth, which are made so as to be easily renewed when worn, being fixed to the lip of the bucket by countersunk bolts and nuts. On the top of the bucket are fixed two plates strongly gusseted, between which the lower end of the arm is secured by a through-pin. The two top plates carry the L-shaped hinges riveted to the flap or door. This is fastened by a stout bolt fixed on the outside, opposite to the hinges, and kept closed by a spiral spring protected by a casing. By pulling a cord attached to the bolt this is withdrawn out of its socket and the door falls open by its own weight, and hangs vertically. When the bucket is lowered and brought back again to the bank the door latches itself automatically in closing. The handle or "bale" of the bucket swings on pins fixed about centrally on each side; it is well arched to allow room for the dirt, and is secured to the snatch-block by a pin and strap.

The main lifting-chain passes from the winding-drum of the engine, through the tower and over the pulleys on the top, through the bucket-arm, over a sheave on the end of the jib, round a snatch-block on the handle of the bucket, up to another sheave on the jib, and down again to the snatch-block, obtaining, therefore, a treble purchase.

The capacity of the bucket in the machine employed on the Panama Canal is 1¼ cu. yds. It takes three-quarters of a minute to load and discharge the bucket and return it to its former position. Moving forward, laying rails, and waiting for cars may be set down as a deduction of 10 minutes per hour, leaving 50 minutes for cutting, which gives, say, 60 as the number of bucket-loads per hour, or 600 per day of 10 hours. The theoretical capacity of this machine can therefore be assumed at 750 cu. yds. per day. In practical work, however, only two-thirds of its theoretical efficiency is obtained, and it is safe to calculate its output at 500 cu. yds. per day.

The working expenses of this machine can be calculated at

$17.50, divided into the following items: One engineer at $3, a craneman and a foreman at $2 each, four men at $1.50, one ton of coal, and 50 cents for water, oil, and waste. The cost of removing a cubic yard of earth at its theoretical efficiency will be 2.32 cents, and at its practical efficiency, 3.5 cents.

Thew Automatic Steam-shovel.—From the description of the two machines given above, it can be easily seen that no essential

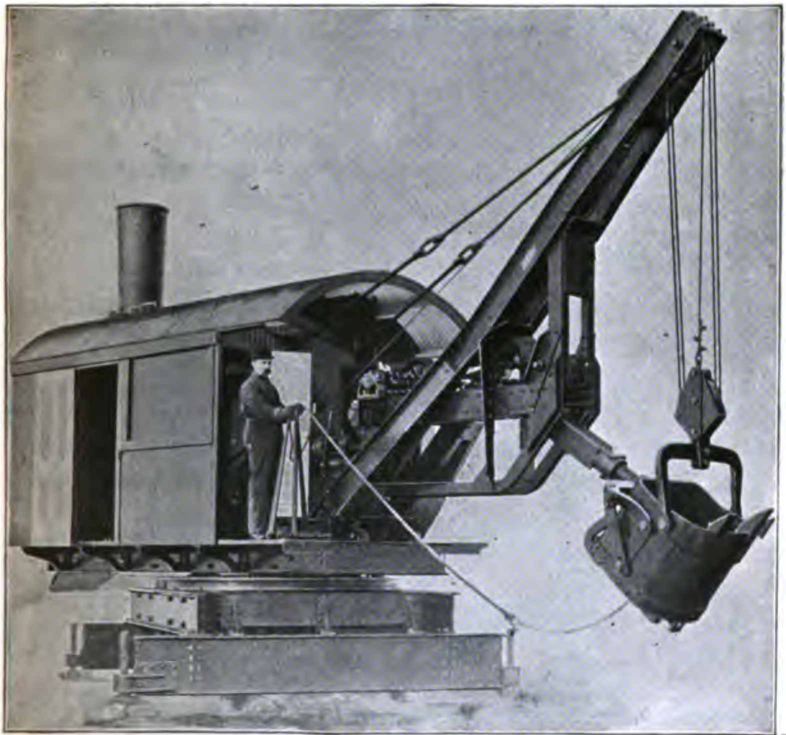


FIG. 52.

difference in design exists between the American steam-shovel and the English navvy; but a somewhat radical departure in the design of steam-shovels was taken by the Thew Automatic Shovel Company of Lorain, Ohio, whose shovel, Fig. 52, is thus illustrated by the *Engineering News*, Vol. XLV, p. 260. The chief feature of novelty in the machine is found in the construction of the swinging

boom and the method of manipulating the dipper, particularly with reference to the crowding motion. The dipper-arm is hinged to a carriage or trolley which slides horizontally along a trackway, forming part of the boom structure. The dipper is forced into the material to be excavated by advancing this carriage, thereby shifting the point of rotation for the dipper. This sliding carriage is of steel, with replaceable friction-shoes, and is actuated by wire cables operating over drums geared to the boom engine. Proper tension for the cables is secured by adjustment at the drums, which are double, one part being keyed to the shaft, the other loose with suitable provision for clamping to the fixed portion when in desired position. A throttle-lever, manipulated by the craneman, controls the movement of the trolley, a trip at each end of the horizontal stroke cutting off the steam automatically and obviating any danger from carelessness on the part of the operator.

The dipper-arm is of rectangular cross-section and adjustable as to the length, the lower portion telescoping into the upper and being held in place by a lock which engages the teeth of a rack attached to the lower member. This lock is retained in position by a spring and is operated by means of a lever conveniently accessible from the craneman's platform. The lock being released, the length of arm can be adjusted by moving the trolley back or forward as desired.

The combination of the boom with the trolley trackway is claimed to afford a very stiff construction, the slight clearance required for the upper end of dipper-arm enabling the rigid cross connection of the two sides at frequent intervals. The boom girder is reinforced by Z bars, which form a guide for the dipper-handle, thereby greatly increasing the lateral rigidity in operation.

The boom is suspended from the A-frame head by wire guy cables. A further departure from generally accepted methods is found in the use of wire cables instead of chains for the hoisting and swinging motions. With sheaves of proper diameter it is claimed that most satisfactory results are secured, the decrease in friction and in the weight of operating parts being of considerable importance. Additional advantages which are claimed are the

noiselessness of operation and the lessening of unexpected breakage, wire cable in almost every instance giving ample warning of failure by its exterior appearance.

In general construction the excavator is of the A-frame type, with independent reversing-engines for the hoisting, swinging, and crowding motions. Particular attention has been paid to the design of the car body, especially with reference to the rigid connection of the front portion of the car frame, which carries the turntable, boom, A frame, and jack-stays, and which must withstand the severest strains of operation.

The practical value of this new steam-shovel has been fully demonstrated not only in the excavator just described, but also in single-truck shovels of smaller capacity, of which a large number are now in use for hauling ore, limestone, and fuel in blast-furnace-yards, and on the docks at Lake Erie ports, as well as in placer mining and general excavating work.

"The steam-shovel, or navvy," Mr. Ruston says, "excavates and delivers into wagons any material capable of being cut, such as sand, gravel, chalk, and clays of all kinds, digging out with equal facility the hardest and toughest, such as require blasting when worked by hand. It can also deal with these materials when thickly interspersed with stones and heavy boulders; and without being unduly strained it cuts through seams of flint, shale, slate, or even sandstone, which may intersect the face of the excavation it is at work upon."

The cutting edge of the bucket is never at a height greater than 14 ft. from the ground, but the steam-shovel may cut faces of much greater heights because it undermines the bank, thus causing the fall of the upper part, which then may be easily taken up by the bucket; or the fall of the upper part of the bank may be obtained by workmen working with levers and crowbars, and when the earth is at the foot of the bank it can be picked up by the bucket. Consequently the machine can cut banks of 20 and 25 ft. and even greater heights, this, however, chiefly depending upon the looseness of the soil.

The steam-shovel cuts its own way and is a very valuable

machine in cutting for single-track roads when both sides may be reached on a single advance. Its efficiency, as in the continuous up-diggers, depends mainly upon the arrangement of the transportation service; it is greater when two tracks can be provided, one on each side, in order to have always empty cars on hand and ready to be filled. But it also does very efficient work in excavating large trenches; then the transportation will be done by one track, as will be seen in a succeeding chapter.

In regard to the efficiency of the steam-shovel Mr. A. W. Robinson, in the March, 1903, number of the *Engineering Magazine,* describing a steam-shovel of his own design and built by the Bucyrus Company of Milwaukee, Wis., says: "The steam-shovel handles a dipper of 3½ cu. yds. capacity four times a minute, so that in a good bank when it can fill its dipper the rate of work is 14 cu. yds. per minute. It can make a cut 55 ft. wide and dump its load 16 ft. above the rail. It is worked by a crew of three men on the machine and two to five laborers in the pit, and the coal consumption is about 1½ tons per 10 hours. This shovel has a record of 5880 cu. yds. of gravel loaded on cars in 12 hours and 45,000 cu. yds. in 9 days.

To make the great capacity of this shovel available it is necessary to provide car service of large capacity and as nearly continuous as possible. Trains of twenty-five cars, each holding twenty or more cubic yards, and hauled by powerful locomotives, were used and served past the shovel on a through track, and as soon as one was loaded its place was taken by a second train.

From this it can be deduced that notwithstanding its machine was working under the most favorable conditions, yet the maximum working capacity was only half of its technical efficiency, and consequently in order to be on the safe side it is necessary to consider the work of the machine at one-half of its technical efficiency. Besides, the working capacity chiefly depends upon the arrangement of the trains which are hauling away the excavated materials, and in fact it will be useless to have a powerful and expensive machine of large capacity when it must remain idle

most of the time waiting for the cars to haul away the excavated materials.

Land-dredges.—The second class of intermittent excavating machines comprises all those which dig downward, the excavator standing on the top of the bank being excavated. The machine consists essentially of a derrick or crane from which the bucket is suspended and raised or lowered in the usual manner. This bucket is provided with an arrangement by which it can be closed or opened at will. In operation it is lowered open to the ground, into which it sinks by its own weight; it is then closed, thus grabbing a quantity of earth, raised, and swung over the car, into which the material is discharged by opening the bucket. Excavators of this sort are successfully employed in excavating pits where the material has to be loaded into cars standing on the surface of the ground.

Excavator-buckets are usually either clam-shell or orange-peel buckets. The orange-peel bucket, Fig. 53, patented and built

FIG. 53.

by the Hayward Company of New York, consists of four curved triangular blades, and when closed forms a tight hemispherical receptacle, containing the earth or other excavated material. When open the blades resemble sharp spades which are so adjusted that the maximum digging effect is produced with but a slight tendency to lift the bucket when closing. Horizontal arms are riveted to the blades, and their inner ends are attached to a central block, while the outer ones are hinged to vertical con-

necting-rods, pivoted at their upper ends to the upper center block. The power wheel for closing the bucket is fastened to the lower central block, and is somewhat eccentric in shape, so that it gives its maximum power just as the bucket begins to close. The bucket is well braced, and the shaft is extended on either side to receive the cams, to which are attached the two power chains suspended from pulleys and carried either by the boom of a derrick or by the ropeways of hoisting and conveying machines, and guided by the two drums of the engine. The capacity of the bucket varies from ½ to 1 cu. yd., according to the dimensions. In buckets of 1 cu. yd. capacity the diameter is 5 ft. 7 ins., and the whole bucket is 7 ft. 3 ins. high. When open it is 6 ft. 5 ins. in diameter and 8 ft. 4 ins. high.

The other form of buckets used with intermittent excavating machines is the clam-shell, which takes its name from its similarity to the shell of a clam, as indicated in Fig. 54. The clam-shell

FIG. 54.

bucket is composed of two steel scoops hinged together so that by means of chains they may be opened or closed at the will of the engineer. The bucket excavates in the same manner as the orange-peel bucket.

The clam-shell or grabbing bucket, as it is more properly called, has the edges of the scoops which come in contact with the earth arranged in different ways, according to the material into which it has to work. The edges are made plain when the

machine has to excavate very loose soil, as quicksand, mud, etc. For clay a grab with spaces between the tines is most suitable; for hard, sandy material a grab with interlocking tines, set close together, is necessary; and for gravel and rock an open-tined grab is used as shown by Figs. 55.

These intermittent machines can be operated by one or two chains. When provided with only one chain the grab must necessarily be fitted with additional levers and catches, which are very liable to get out of order; it is wrong in principle to connect

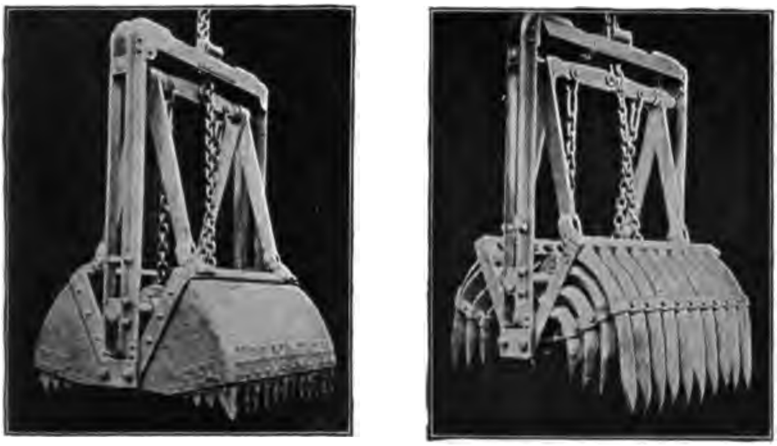


FIG. 55.

intricate working parts with a bucket or grab which is constantly in motion and thus cannot receive proper attention from the driver in lubrication, etc. Besides, with the single chain the bucket must be raised to a certain height to be discharged, while with the double chain the bucket can be opened and closed in any position. It is often necessary to hoist the grab over some projection and lower it again before discharging, which can only be done by means of two chains. For the above reasons the double-chain system is always preferable.

Intermittent digging-machines provided with grabbing-buckets are more usually employed in dredging than in earth excavation on land. Here, however, they are beginning to appear and, perhaps, will be extensively used when better known and appreciated by

engineers and contractors. In cases in which the machine must remain on top of the embankment to be removed, and the excavated materials hauled to the dumping places on roads laid at the level of the top of the embankment, these machines are very efficient and can be advantageously employed. Another great advantage is their ability to excavate from 20 to 30 ft., and even deeper, by simply elongating the hoisting-ropes, an advantage which is not possessed by any other machine.

These down-digging intermittent machines provided with grabbing-buckets are generally mounted on a platform car running on tracks. On the rear end of the platform is located the boiler, which is usually of the vertical type, and often the boiler is accompanied by a wrought-iron water-tank. The engine operating the bucket has two cylinders strongly fixed to cast-iron side frames, which work the lifting-drum without gearing, and are designed for working the self-acting bucket and grab at a great speed, together with all necessary working parts, including lifting, lowering, and turning gear, etc. The jib or boom can be made either of wood or steel, and its lower end stands in the center of a turntable or bull-wheel attached so that it can turn around a pivot center. The upper end of the boom is commanded by means of the rods to the A frame placed at the front of the platform car. From the top of the boom is suspended the grabbing-bucket, whose various movements are regulated by the engineer.

The efficiency of these machines varies with the different kinds of soil and the capacity of the buckets. The Priestman Brothers, Ltd., of London, in their catalogue give the following figures as the approximate quantities of material one man will raise (by steam) per day of ten hours at an average depth of 20 ft.:

Capacity of Bucket or Grab, Size in Cwts.	Tons of Mud.	Sand.	Clay.
10	250	200	150
20	500	400	300
30	650	550	400
40	800	700	500

CHAPTER XI.

METHODS OF HAULING EXCAVATED MATERIALS ON LEVEL ROADS.

UNDER the general name of hauling is included the transportation of excavated materials from the cuts and borrow-pits to the various fills or spoil-banks. Such transportation can be accomplished in so many different ways that it would be almost impossible to give a full description of them all. For sake of convenience, however, and in order to facilitate the review of the most important means of transportation at the disposal of engineers and contractors, hauling will be considered here under four headings, according to the roads along which the materials are hauled:

(1) When the earth is hauled on horizontal roads or roads having only a small gradient.

(2) When the roads are very steep, and consequently the materials must be hauled along inclines.

(3) When the materials are hauled in a vertical direction or hoisted.

(4) When the materials, instead of being transported on roads laid on the ground-surface, are hauled on roads suspended in the air.

For each one of these groups there is a large variety of means of hauling, whose convenience will depend upon many circumstances, but chiefly upon the quantity of material to be transported and the peculiar conditions of the work. These elements should be accurately determined by the engineer and contractor, so as to choose the most efficient means of hauling in the particular case with which they have to deal. It is only by doing this that the work can be performed with the greatest economy.

Speaking of the hauling of excavated materials in a general way, it is necessary to remark that the earths when removed from their natural beds increase in volume and consequently the quantity of earth hauled will be greater than is found from measuring the cut. This is an important item to be remembered, because it is liable to lead to great disappointment, especially when, on account of competition, the bids for the work are prepared with only a very narrow margin. The writer thinks that the swelling of earth after being dug is directly proportional to the cohesion of the material, and consequently the more compact the soil is the greater is the increase of volume. Trautwine says that earth when dug and loosely thrown out swells about one-fifth part, so that a cubic yard in place averages about $1\frac{1}{5}$ or 1.2 cubic yards when dug; or 1 cu. yd. dug is equal to $\frac{5}{6}$ or to 0.8333 of a cubic yard in place. Rock increases in volume from 25 per cent. in the case of small or medium fragments and road metalling to 60 or 70 per cent. in large fragments carelessly piled.

In many public works the quantity of earth hauled away is calculated by counting the carts and wagons, whose capacity has been previously measured. This foolish manner of measuring earth originated the mistaken belief so common among engineers and contractors in this country that earth when placed in embankments will shrink from the volume measured in the pit. Counting the wagons for measuring the hauled earth is, however, very convenient to the contractors. It requires the continuous presence of a representative of one of the contracting parties and consequently a complication in the calculations and greater expense. It is used only on city or state works where the contracting party does not seek for economical work, but to give employment to as many political friends as possible.

HAULING ON HORIZONTAL OR NEARLY HORIZONTAL ROADS.

The easiest way of removing excavated materials is by hauling them along ordinary roads which are horizontal or have only a small gradient. This is performed with different devices or im-

plements whose description will form the subject of the present chapter. Each of the described means of hauling is very efficient, but they cannot be used indiscriminately. In each particular case the engineer has to deal with there is always, according to the distance, one means of hauling which is more convenient than any other. It is for the purpose of determining the most convenient means of hauling in each case that this description has been supplied with tables which can be easily changed according to the data varying with the localities. The calculation has been based on the prices in the city of New York, where the wages are higher than anywhere else.

In hauling materials on ordinary roads it is necessary to take into consideration the grade of the road. Thus, if the road is horizontal or descending, it is its horizontal projection that is considered as the real distance; but if the road has an ascending grade, the distance or length of the haul is given by the formula

$$L(1+0.01a),$$

where L is the horizontal projection of the road, and a a coefficient varying with the grade and with the means of transportation as follows:

When the hauling is done by means of wheelbarrows, carts, or wagons

$$g=1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7,\ 8,\ 9,\ 10\%,$$

and

$$a=5,\ 11,\ 18,\ 25,\ 33,\ 43,\ 54,\ 67,\ 82,\ 100\%;$$

and when by cars running on tracks

$$g=1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7,\ 8,\ 10,\ 12,\ 14,\ 16,\ 20\%;$$

and

$$a=3,\ 8,\ 13,\ 18,\ 23,\ 31,\ 38,\ 56,\ 85,\ 104,\ 124,\ 150,\ 180\%.$$

In practical work and for rough calculation it is usually assumed that the hauling of the materials done by means of wheelbarrows on roads having a grade varying from 1 to 8 per cent. is nine-tenths of what it will be if done on horizontal roads, and

with carts and wagons hauled by horses on good roads of the same inclination as above eight-tenths. When the hauling is done on newly opened roads, without any road-bed or paving and with an inclination not greater than 7 per cent., the efficiency of the hauling is only eight-tenths of what it will be if done on horizontal roads.

For sake of simplicity and to facilitate the review of the various means of hauling materials on horizontal roads, they will be divided in regard to the motive power employed and grouped as follows:

- **Materials hauled by**
  - **Animal. Power.**
    - **Man..........**
      - **Wheelbarrows.**
      - **Hand-carts.**
    - **Horse.........**
      - **Drag and wheel scrapers.**
      - **Carts and wagons.**
      - **Cars on narrow-gauge tracks**
  - **Mechanical Power.**
    - **Steam or Electricity...**
      - **Cars on narrow-gauge tracks**
      - **Cars on standard-gauge tracks.**

Wheelbarrow.—The oldest and the simplest means of hauling small quantities of earth to a short distance is by wheelbarrows. This implement consists of a wooden box resting on a frame made of two inclined beams converging at the front and having between their forward ends a small wheel. At the rear end of the box there are two short legs, so that the barrow when at rest will stand on these three supports. The diverging beams end in the shape of handles. There are barrows of d fferent patterns on the market, and the best is the one in which the distance apart of the center of gravity of the load and the wheel-axle is the smallest possible. It would be also convenient to have the wheel of large radius, but such a construction would increase the weight of the barrow and it is thus advisable to make the radius of the wheel between 15½ and 19 ins. The box is arranged in such a way as to have the load as near as possible to the front wheel when in motion. The unloading of the material from wheelbarrows is easily done. When the dumping place has been reached, the laborer raises up the handles so as to throw the weight on the front wheel, then with one hand he pushes down one of the handles,

while he raises up the other handle, thus causing the barrow to tilt and unload its contents.

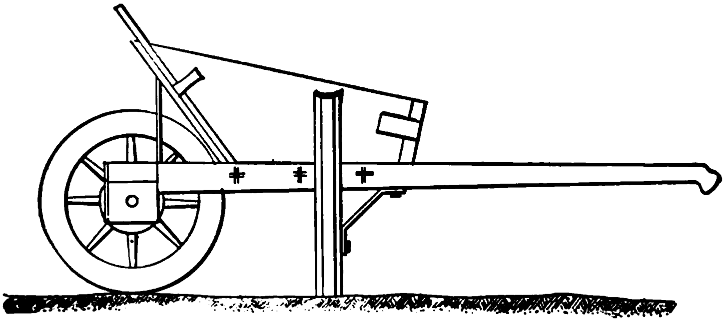


FIG. 56.

Fig. 56 represents the wheelbarrow used in Germany of 3 cu. ft. capacity. The box is above the handles, and the sides flare out from the bottom. Fig. 57 represents the ordinary American wheelbarrow, in which the box is flat like a tray, the diameter of the wheel is 17 ins., and the capacity varies from 3 to 5 cu. ft.

FIG. 57.

Wheelbarrows are also constructed with the tray of iron, and others are made entirely of iron, but their great cost is a serious obstacle to their employment in public works where these vehicles are roughly handled. When they are made of wood they can be easily repaired by any ordinary carpenter, but when made of

iron the repairing is more expensive, the services of a skilled mechanic being then required.

Many improvements have been lately made to wheelbarrows which are covered by patents; for instance, the Allen spring barrow, built by C. W. Hunt Company of New York, illustrated in Fig. 58. This barrow is provided with springs under the bear-

FIG. 58.

ings of the wheel, so that it is much easier to handle and runs over irregularities without violent shocks to either the workman or the load. They are built of different sizes, with a capacity varying from 3½ to 8 cu. ft. They are quite expensive, their price being from $15.50 to $20.

The cost of hauling a unit of volume of earth by means of wheelbarrows depends upon the distance. Assuming that a man with a load can travel 10 miles a day, he will carry loads only half of this distance, the other half being employed in returning with the empty barrow. It is evident that the shorter the distance the greater will be the number of trips he can make, carrying each time 3 cu. ft. of earth; and since the cost of hauling is given by the wage of the laborer, the greater the quantity of earth carried in a day the smaller will be the cost of hauling per unit of volume. The following table gives the number of trips and the quantity of material carried by a laborer with wheelbarrow, at various distances, also the cost of the work per cubic yard. These figures have been deduced by considering a day's work as 10 hours and the wage of the laborer, $1.50 per day.

From this table it is clearly seen that wheelbarrows are very convenient for small distances, but that this manner of hauling becomes too expensive for distances of 300 ft. or more.

Distance, Feet.	Number of Round Trips.	Quantity of Earth Carried.		Cost per Cubic Yard.
		Cubic Feet.	Cubic Yards.	
50	528	1584	58.44	$0.025
100	264	792	29.22	0.050
150	170	510	19	0.079
200	132	396	14.61	0.100
250	106	318	12	0.125
300	88	264	10	0.150
350	75	225	8	0.187
400	66	198	7.3	0.205
450	59	177	6.5	0.230
500	53	159	5.9	0.254

Hand-carts.—It is desirable to increase the capacity of the vehicle with the increasing of the distance of transportation of the excavated materials. This is usually done by means of hand-carts, which are small carts having a capacity varying from 7 to 10 cu. ft. They are composed of a wooden frame fixed to a platform of the same material and surrounded by boards forming the box and resting on a single pair of wheels 3 or 4 ft. in diameter. In continuation of the frame, at the center of the front of the box there is a shaft about 5 ft. long ending with a cross-piece. The cart is moved by two men who place themselves behind this cross-piece and push. To dump the cart the men turn so as to have the rear of the cart on the edge of the dump, then they remove the rear board of the box and raise up the shaft; the box turning over the axle of the wheels takes an inclined position, and the excavated earth it contained falls to the ground. Hand-carts are very commonly employed in Germany, but very seldom if ever in this country or in England.

The cost of hauling earth by means of hand-carts is given by the wages of the two laborers. It varies with the distance the excavated materials have to be transported. The following table indicates the cost of hauling earth at various distances by means of a hand-cart of 8 cu. ft. capacity, hauled by two men at $1.50 per day and traveling with load 12 miles per day of 10 hours:

Distance, Feet.	Number of Round Trips.	Quantity of Earth Carried in a Day.		Cost per Cubic Yard.
		Cubic Feet.	Cubic Yards.	
200	158	1264	47	$0.064
300	105	844	31.3	0.096
400	80	640	23.7	0.128
500	63	504	18.7	0.160
600	53	422	15.6	0.193
700	45	340	12.6	0.237
800	40	320	11.8	0.254
900	35	280	10.4	0.288
1000	31	252	9.4	0.320

Drag Scrapers.—Another means of hauling away earth which has been already removed from its natural position is by drag scrapers (Figs. 59–61). These consist of a box made up of smooth sheet steel open on the front, where it is provided with a sharp cutting edge. Near the front and pivoted to the two sides of the

FIG. 59.

FIG. 60.

FIG. 61.

box there is a steel bail in the shape of an inverted U, furnished with an eye in the center to which the horses are hitched. At the rear end the box is provided with two wooden handles for the filling and dumping the scraper. Each drag scraper requires a team of two horses, with a driver who operates the scraper. To fill the box the driver raises up the handles to a small angle so that the cutting edge penetrates the earth, and the scoop is filled with the dirt while the horses are moving. He then drops the handles,

and the loaded scoop is dragged along the ground. When the dumping place has been reached the operator raises up the handles until the front edge engages the soil, and the scoop rotates around the pivots of the bail and the load falls onto the ground.

The two parts of the scraper subjected to great wear are the bottom and the sharp edge. The bottom of the scraper especially, being dragged on the ground, is very soon worn out, and to prevent this it is reinforced either by runners placed longitudinally, as indicated in Fig. 59, or by an extra flat steel bottom, as shown in Fig. 60, which may be removed and changed when worn. The cutting edge, especially when working through gravel, hard-pan, etc., is also easily ruined, and it is better to have it made interchangeable.

The capacity of drag scrapers varies from 4½ to 5½ cu. ft. They are very efficient in the excavation of earth not deeper than 2½ or 3 ft. and where the materials have to be hauled to a distance not greater than 200 ft.

Drag scrapers can be considered as self-loading and dumping vehicles, and they are used in hauling away materials which have been broken up by means of a plow. It is in connection with plows and for short hauls that these means of transportation are most efficient.

The cost of hauling by means of drag scrapers is easily calculated; it depends upon the distance of the haul. The only expenses are the hiring of the team and the wage of the driver, the interest of the capital invested in the scraper, as well as its sinking fund, being too small to be taken into consideration. The cost of hiring the team is about $5, while the driver gets $1.50 a day, so that the total expenses will amount to $6.50 per day. Since the driver must walk continuously, it is considered that the horses will drive 15 miles. The capacity of the scraper being on the average 5 cu. ft., the number of trips, including also the return for loading, and the cost per unit volume are given in the following table:

Distance, Feet.	Number of Trips.	Cubic Yards Hauled per Day.	Cost of Hauling One Cubic Yard.
100	400	74	$0.09
150	300	55.5	0.116
200	200	37	0.18
300	150	27.5	0.23
400	100	18.5	0.34
500	80	15	0.43
600	66	11	0.60

Wheeled Scrapers.—Wheeled scrapers are more convenient than drag scrapers for conveying materials. These consist of a box or pan made of one piece of sheet steel bent without heating. Their dimensions are 3×3 ft.×15 ins. deep, and when full contain from ⅓ to ½ cu. yd. The box, as in the drag scraper, is open in front and can be raised and lowered, and also revolved around a horizontal axis by means of a lever. The wheels are 36 ins. in diameter and are provided with broad tires to prevent them from sinking into the loose earth.

To fill the box while the horses are moving and dragging the machine forward the driver pulls up the lever, and the pan hits the ground at a small angle which is regulated automatically. The edge of the pan scrapes the soil, and the box is filled with earth; then the driver pulls down the lever, and the pan is raised about 1 ft. from the ground, and in this position it travels. When the dumping place has been reached the driver pulls up the lever, the front edge of the pan engages the earth, and the box turns around its axis, thus unloading its contents. Wheeled scrapers, consequently, can be considered as self-loading and dumping cars.

Wheeled scrapers of different forms are found on the market. Notwithstanding they are built by different manufacturers and are all covered by patents, they are all similar in the essential parts and vary only in details, as, for instance, levers, attachments, latches, special arrangements for unloading, etc. Fig. 62 represents one of the wheeled scrapers built by the Western Wheeled Scraper Company, of Aurora, Ill.

Wheeled scrapers are made of different sizes, their capacity

varying from 9 to 14 cu. ft. The smaller machines require a team of two horses, with a driver who handles the lever and regulates the work of the scraper; the larger ones require another man besides the driver. The smaller sizes will remove the earth cheaper, on a short haul, than the drag scraper, while the larger sizes are convenient for long hauls. These means of transportation are very convenient in excavations which are not deeper than 3 or 4 ft., as, for instance, in preparing the work for more

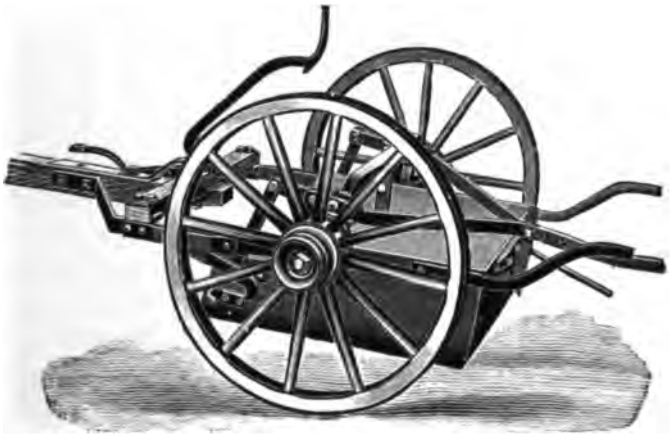


FIG. 62.

powerful machines or removing the earth above rock which has to be blasted. In the excavation of the Chicago Drainage Canal wheeled scrapers were extensively used, and they hauled up to 46 cu. yds. per day.

The efficiency of the work, however, depends upon the size of the scoop and the distance to which the material is to be hauled. In the following table are given the quantity of the material hauled by wheeled scrapers of 9 and 14 cu. ft. capacity, and the cost for the various distances. The prices are calculated on the basis of those paid in New York, and when the work is done in the country the prices given should be reduced at least one-third.

From this table it is seen that the cost of hauling material by means of wheeled scrapers increases with the distance, and even when

reduced one-third the prices given remain high. To remedy this the Western Wheeled Scraper Company put on the market a machine which was a combination of scraper and wagon. This machine

Distance, Feet.	Number of Trips.	Scoop 9 Cubic Feet; Amount of Material Hauled in a Day in Cubic Yards.	Scoop 14 Cubic Feet; Amount of Material Hauled in a Day in Cubic Yards.	Cost per Cubic Yard.	
				Nine Cubic-foot Scoop.	Fourteen Cubic-foot Scoop.
200	200	70	103	$0.093	$0.077
300	133	44	70	0.147	0.114
400	100	33	51.5	0.200	0.115
500	80	27	41.3	0.240	0.193
600	66	22	34.2	0.290	0.234
700	57	19	29	0.370	0.276
800	50	16.5	25.7	0.400	0.311
900	44	14.7	21.7	0.44	0.366
1000	40	13	20	0.50	0.400

consisted of two wheeled scrapers of large capacity carried on a frame supported by four wheels. The two scrapers were operated independently from one another; the front pan was loaded first and was raised to its place, the second pan was then lowered and loaded and raised. Since the two pans had together a capacity of 1⅓ cu. yds., they required from two to three horses to pull them.

FIG. 63.

FIG. 64

But these machines have not met with success since their construction has been discontinued.

Another but simpler machine which found great favor with contractors, especially in handling the earth that might be dumped to a distant point, is the one illustrated in Figs. 63 and 64. This consists of an ordinary wheeled scraper of large capacity, the only difference being that it is provided with a front scoop closing the

pan of the scraper and firmly retaining its contents. In this manner the earth loaded into the scraper will be carried to the dumping place without spreading it all over the road, as usually happens with the ordinary scrapers. The front scoop is fixed and engages the scraper when it is raised and loaded. Fig. 63 shows the machine closed, while Fig. 64 shows the machine when the scraper is lowered and ready to be loaded. Such a wheeled scraper can be considered as a self-loading and dumping cart, and it is certainly very convenient, since it eliminates two expensive items entering into the cost of the earthworks, viz., the loading and unloading of the earth into the carts.

Carts and Wagons.—The transportation of excavated materials to a great distance is usually done by larger vehicles hauled by horses. These vehicles vary greatly, but are either carts or wagons, a distinction which is made according to the number of wheels. They are called carts when provided with only two wheels of large dimensions, while those provided with four wheels —two small ones in front and two larger ones behind—are called wagons. Both carts and wagons can be divided again into ordinary and self-dumping, according to whether the material is unloaded by hand or dumped automatically.

Carts.—Ordinary carts, called also equilibrium carts, are very similar to the hand-carts described above, with the difference that they are of larger dimensions. They consist of two large wheels, from 5 to 6 ft. in diameter, and a box firmly fixed to the axle of the wheels and provided with two shafts to which the horse is hitched. The capacity of the cart varies from 20 cu. ft. to 1 cu. yd. It affords a very convenient means of transportation on roads having even an inclination of 8 per cent. To unload the cart, usually the driver detaches the horse and pulls up the shafts, and the cart revolving around its axle causes the material to fall off.

Dump-carts.—Very similar to ordinary carts are those which dump the materials without being compelled to unhitch the horse. These carts are commonly known as dump-carts, and are constructed of different materials and shapes. The one illus-

trated in Fig. 65 has the shafts fixed to the axle of the wheels, and the box is provided with two supports at its bottom and upon which it rests, and may revolve around the axle. The body of the cart is kept in a horizontal position by means of two spurs projecting at the front; the shafts are provided with two eyes

FIG. 65.

through which passes an iron or wooden bar, for keeping the spurs of the box flush with the shafts. To unload the cart this bar is removed, and since the center of gravity is just a little at the rear of the axle, a simple push by the driver will rotate the box around the axle, and the material will fall from the rear end, the end-board having been previously removed. Dump-carts are also made of iron, as, for instance, the Hill dump-cart, represented in Fig. 66, which is extensively used in the city of New

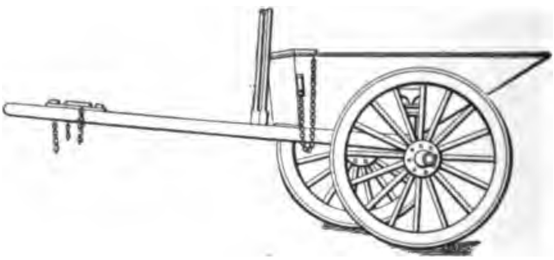


FIG. 66.

York. The high prices charged for these new and patented dump-carts prevent their extensive use in the hauling of the earth excavated for engineering purposes.

Ordinary Wagons.—The strength of animals is more conveniently utilized when they are working in teams, as will be seen later on, and in such cases the materials are carried away by means of wagons. These consist of a four-wheeled truck made up of heavy beams with a platform surrounded by boards so as to form a box in which the materials are deposited. The front wheels are of smaller diameter and their axle is pivoted to the frame of the truck so that these wheels may go under the platform and the wagon turn in a small circle. Attached to the axle of the front wheels there is a shaft to which the horses are hitched. This ordinary wagon does not afford the most convenient way of carting excavated materials, because the earth must be unloaded by hand, and this expensive item will tend to greatly increase the cost of hauling on account of the labor and time required.

Dumping-wagons.—Dumping-wagons are more convenient, and consequently more commonly employed in the transportation of materials in public works. These are similar to ordinary wagons, with the difference that they are provided with some arrangement which will allow the dumping of its contents. There are numerous dumping wagons on the market, many of them still covered by patents, but those employed in the hauling of earth can be grouped as wagons in which the bottom is removed and the materials fall between the wheels, or in which the platform of the vehicle slides on the truck and the material is dumped from the rear end of the wagon.

The simplest form of dumping-wagons of the first group, in which the bottom of the platform is removed and the material falls between the wheels, consists of an ordinary wagon in which the platform is composed of several square-edged beams with round projecting ends. They are generally 4×4 ins., and are placed close together and resting on the frame of the wagon. When the driver wants to unload the wagon he pulls out one of these beams. All the others then become loose and the whole platform may be easily removed, and the material will of course fall on the ground and between the wheels. This form of wagon,

although commonly used in the Highway Department of the city of New York, is not advisable on public works on account of the great length of time required in unloading, and this is perhaps the reason why it was deemed desirable by the New York politicians.

More convenient than the wagon just described, but of the same type is the Watson dump-wagon illustrated in Fig. 67. The wagon is so constructed that the front wheels may pass underneath the body of the truck, thus allowing the wagon to turn in a small circle. The platform is made up of two parts joined at the middle, but hinged to the sides of the wagon in such a manner

FIG. 67.

that they may be opened and closed as the leaves of a door. The opening and closing of the bottom is accomplished by means of chains passing over gears at the sides of the frame and regulated by a sprocket-wheel moved by a lever located near the driver's seat. By pulling the lever the chains loosen and the two parts forming the bottom of the wagon are opened and the contained material falls between the wheels. When the wagon is emptied, the driver by reversing the lever causes the closing of the bottom, and the wagon is in position to be again loaded with earth. The opening and closing of the wagon, and consequently the dumping operation, can be made without any inconvenience and while the horses are moving, so that not a single instant is lost for the

unloading of the wagon. It is no wonder that this kind of wagon has met with the greatest success, and that they are extensively employed in public works for the transportation of materials.

Dumping-wagons of this type are found in great numbers on the market; they are all built on the same principle, but vary in details. The differences chiefly consist in the arrangement of the chains for the opening and closing of the bottom of the wagon, in the construction and arrangement of the sprocket-wheels and guiding-sheaves, in the lever, etc. These details, however, are too insignificant to be considered in a book like this, where only the various types of machines and implements used by engineers and contractors are briefly described.

A different type of dumping-wagon is the one in which the box rests on a truck which is provided with a platform. This is a little inclined toward the rear and is furnished with iron bands so as to offer a smooth surface to the box in sliding. To further facilitate the sliding the lower part of the box is provided with iron rollers. During the transportation, while the wagon is loaded, the box is fixed to the front of the truck by means of heavy iron hooks. To unload the wagon the driver releases the box from the truck by disengaging the hooks, and the box slides along the iron guides and turns around the hind edge of the truck and assumes the position indicated in Fig. 68.

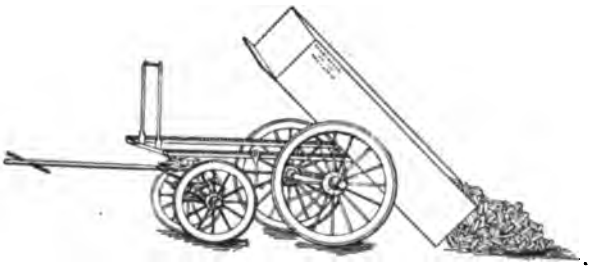


FIG. 68.

The dumping of the material from these wagons, while it does not require any work, will take up some time, since it is necessary to stop the horses, the driver has to loosen the box, and when

empty it must be raised up and fastened again to the truck. There is no doubt that a great deal of time will be necessary for these various operations, and for this reason these wagons are not so convenient for the transportation of excavated earth as the contractor's dump-wagons are; but they are more commonly employed in the transportation of building materials, as bricks, sand, building stones, etc.

There is still another type of dumping-wagons, in which the box is fixed to the truck during the hauling, but is so arranged that it may rotate around an axis. A new dumping-wagon re-

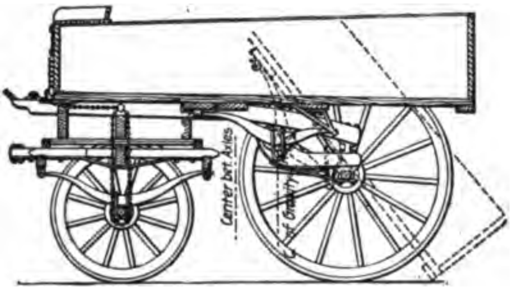


FIG. 69.

cently patented and built by the Shadbolt Manufacturing Company of Brooklyn, and extensively used in the construction of the New York Rapid Transit Subway, is designed on this principle. The body of the wagon (Fig. 69) is balanced on the rear springs so that it is easily tilted without the use of any special mechanism, the springs resting on a bar across the frame. The sockets in which this bar turns are set in the frame sides at a point in front of the rear axle just sufficient to throw part of the load on the front axle, thereby bringing the center of gravity about 1 ft. back of a certain point between the axles, which practice has shown to be the best distribution of load to secure the easiest draught with wheels of the relative height of those in common use. A chain is attached to the front end of the car, and passes under the front axle, relieving the strain caused by the act of dumping, the front springs serving as cushions. The chain can be shortened or lengthened

at will, thereby determining the angle at which the wagon must be tilted, according to the different conditions that govern the operation, such as the nature of the load, the site where it is to be dumped, etc.

The capacity of carts is about 1 cu. yd., while that of wagons varies between 1½ and 2 cu. yds. For the reason explained at p. 281, in hauling earth, wagons should always be preferred to carts, and the type of vehicle selected should be such as will do the work at the smallest cost.

In calculating the cost of hauling by carts and wagons the following items should be considered: (1) The daily wages for team and driver, including also the hiring of the cart; (2) the time required for loading; (3) the distance of hauling; (4) the time required for unloading the car and (5) the time employed on the return trip. Comparing these various items with the number of miles that a team may travel in a day and with the number of round trips that can be made in a day, the cost of hauling a unit of volume of material to a given distance will be easily found. As a rule it is assumed that the transportation of the excavated materials by means of carts and wagons is not convenient for distances greater than a mile.

Assuming the cost of hiring a horse and cart, the wages of the driver being included, to be $3.50 per day, and that of hiring a team of horses with wagon and driver to be $5, and the capacity of the cart be 1 cu. yd. and that of the wagon 2 cu. yds., and that a single horse with a cart may travel 15 miles per day while the team of horses hitched to the wagon will travel 20 miles; the cost of hauling the unit of volume of earth at the various distances will be as given in the following table.

The hauling of the stones, obtained from the excavations through rock, is usually done by means of ordinary carts and wagons just described. To easily load the stones into these vehicles it is necessary to break them into small fragments, and this becomes an expensive item when the rock is removed from its natural bed by means of blasting, in which large stones are detached from the bank. To haul away these large stones by means of ordinary

Distances in Feet.	One Horse and Cart.			Two Horses and Wagon.		
	Number of Round Trips.	Quantity of Earth Hauled per Cubic Yard.	Cost per Cubic Yard.	Number of Round Trips.	Quantity of Earth Hauled per Cubic Yard.	Cost per Cubic Yard.
500	79	79	$0.044	105	210	$0.024
1,000	40	40	0.087	53	106	0.047
1,500	26	26	0.134	35	70	0.072
2,000	20	20	0.174	26	52	0.094
2,500	16	16	0.22	21	42	0.12
3,000	13	13	0.268	17	34	0.15
4,000	10	10	0.348	13	26	0.188
5,000	8	8	0.445	10	20	0.25
6,000	7	7	0.500	8	16	0.31
7,000	6	6	0.583	7	14	0.36
8,000	5	5	0.696	6	12	0.41
9,000	4	4	0.890	5	10	0.50
10,000	3	3	1.166	4	8	0.62

carts and wagons presents a serious difficulty, not so much in regard to loading the stones into the carts as in dumping them. Here, if the vehicle is self-dumping, the sudden strain produced by the fall of such a heavy stone will seriously affect the delicate parts of the carts—otherwise it will require a long time and the employment of several men to effect the unloading of the larger stones of 1, 2, and 2½ tons each. To avoid this inconvenience special cars are constructed.

In small excavations, especially in country works, one of the most convenient vehicles for hauling large stones is the stone-boat. This consists of three heavy boards made of hard, smooth-grained wood, held together by means of two crosspieces at the ends, strongly nailed or bolted, and provided with an iron hook in front, to which the beam is hitched, as indicated in Fig. 70. On this very heavy stones can be easily loaded with crowbars or hand-levers.

The stone-boat slides easily even in the softest ground and in some cases it may be found convenient even for hauling earth, especially when the ground is too soft for wagons or wheels of any kind. When the stone-boat is used for carrying the earth, one or two strips of board may be nailed on the edges. This cart is easily loaded, since the shovelers do not have to raise the material,

as in ordinary carts and wagons, and in many cases earth can be hauled cheaper in this way than in any other. The stone-boat

FIG. 70.

illustrated in the figure is the one built by G. C. Pollard of Brooklyn, N. Y.

The stone-boat cannot be employed in case the stones have to be hauled on paved roads, especially along the city streets, and then a specially constructed wagon is usually employed. This consists of a four-wheel truck in which the front and rear wheels are separated. The platform of the car is made up of heavy planks reinforced with iron bands; and it is very low, being, as a rule, not more than 1 ft. from the ground. The axle of the rear wheels is above the plane of the platform, and to protect it from twisting under the weight of a large stone concentrated only at one point, there is a wooden incline arranged in the manner clearly indicated in Fig. 71.

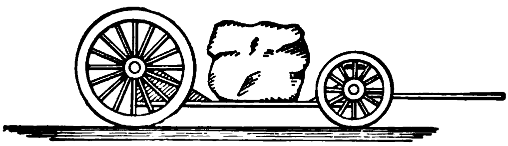


FIG. 71.

The center plank of the platform is longer, and its extreme is provided with a hook which engages a chain firmly fixed in some way to the axle of the front wheels of the truck. Such an arrangement

permits the car to turn even on sharp curves. The advantage of these cars is that they can be easily loaded and unloaded. The platform is so low that even large stones can be easily placed there by means of levers and without the necessity of having cranes or derricks. The operation of unloading the car is very simple; a crowbar is applied as a lever under the sides of the platform of the car, so that it is raised up just a little, but enough to disengage the chain from the hook; the front wheels are thus separated from the car, and the platform, deprived of one support, will form now an inclined plane, along which the large stones may easily descend. Fig. 71 illustrates one of these cars as commonly employed in the city of New York.

CHAPTER XII.

HAULING EXCAVATED MATERIALS ON HORIZONTAL ROADS.

THE roads used to haul the excavated materials for earthworks are generally without paving, and consequently their surface, being of very loose material, offers great resistance to traction. Hence in works of some magnitude and when the grade is not greater than 3 per cent., the hauling is more conveniently done by cars running on temporary tracks, or by means of so-called *industrial railways.* Industrial railways were invented by Decauville of Petit Bourg, France, and are now built by different firms all over the world, as, for instance, by Legrand of Mons, Belgium; Arthur Koppel of Berlin; Kerr, Stuart & Co., Ltd., England, and in America by C. W. Hunt Company of New York; Steubner of Long Island City, N. Y.; Ryan & McDonald of Baltimore, and many others.

To begin with the tracks: they generally vary in form and dimensions, depending upon the load that they have to carry. Those built in this country are of the usual American standard rail section of small dimensions, varying usually from 12 to 20 lbs. per lineal yard. The smaller sizes are employed to support light loads not more than 6000 lbs., whilst the larger can support cars loaded with 15,000 lbs. The two rails are riveted to steel cross-ties, and the truck is made in sections varying from 16 to 20 ft. in length. One end of each section is provided with fish-plates, one end of which is riveted to the rails, whilst the other projects and is bolted to the succeeding section of track. Fig. 72 shows the

FIG. 72.

end of one rail with the attached fish-plates, ready to receive the succeeding section; and Fig. 73 illustrates one section of track as manufactured by Arthur Koppel of Berlin. Similar sections are made in curves of 12-ft. radius or more, and are con-

FIG. 73.

nected to the straight line by means of fish-plates, as described above.

The gauge of industrial railways generally varies from 20 to 24 ins., and these gauges have been found convenient. The gauge has not a great influence upon the load to be carried on the rails, since heavy weights can be easily hauled on narrow-gauge tracks provided the rails are strong enough to stand the pressure. The total weight of a straight section, with 12-lb. rails and 20-in. gauge, complete with its cross-ties, is about 28 lbs. per lineal yard, while the weight of the same section, with rails of 24-in. gauge, is 28½ lbs. per yard. One section being from 16 to 20 ft. long, its weight will vary between 112 lbs. for a section 16 ft. long, 20-in. gauge, and 12-lb. rail, and 380 lbs. for a 20-ft. section with 24-in. gauge and 20-lb. rails. These are loads which may be easily taken up and transferred by two men.

The cross-ties of industrial railways are of steel, and are usually made of a convex form, so that the earth will be compressed underneath, thus forming a kind of incompressible cushion which will prevent the sinking of the track under the load. In Fig. 74 is shown the cross-section of a cross-tie built by Arthur Kappel of Berlin. The cross-ties are generally constructed with a large bearing surface on the foundation, to support the load; this area in proportion to the load is nearly double that of the ordinary railroad cross-tie. They are placed about 3 ft. apart, center to center, and there is one cross-tie near the end of each section, so

that when the line is placed on the ground and ready for service the cross-ties are not equally spaced, but are closer near the joints

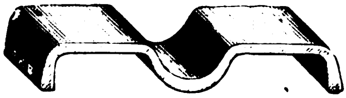


FIG. 74.

of the rails. Cross-ties are usually provided with two or three holes, so that they may be nailed to planks laid underneath in order to increase their bearing, thus making still more difficult

FIG. 75.

the sinking of the tracks under the load, and this is generally done when the ground is very loose and wet. The rails are firmly riveted to the cross-ties, but in some cases, for convenience of

shipping and to avoid high duties in importing these industrial railways into other countries, the cross-ties are detached and provided with clips which will firmly hold in place the lower flange of the rail.

Industrial railways like ordinary railroads are provided with switches. These are usually arranged with a special rail on a curve of 12-ft. radius and riveted up solid to the cross-ties, having the switch-points and frog complete. Switches are made to match the portable tracks, and are supplied either with a right or a left curve as in Fig. 75. There are also three-way switches, as indicated in the same figure. The switch-point consists of a tongue, which may be moved around a pivot. The points are usually moved by the workmen, but with heavier rails, and when the railway is to be used for a long time, a switch-stand mounted on steel sleepers is employed, and these are built to match any line.

In connection with industrial railways there are also turntables in order to allow the cars to change direction at right angles to the line. These consist of two circular steel plates, the lower one having a grooved ring in which are placed balls made of hardened steel acting as rollers, and kept in place by a small groove underneath the upper plate. A center pivot keeps the two plates concentric, and while the lower plate is fixed to the ground the upper one may revolve around this central pivot. On the upper plate are inserted pieces of steel rails at right angles, and in the manner indicated in Fig. 76. The turntable is sometimes provided with brakes to keep the upper plate fixed to the right place, and then the lower plate is provided with slots to receive the brake which is attached to the upper plate. The platform of the turntable is sometimes made of wood, but in any case the ring containing the balls acting as rollers, as well as the casing of the pivot, are always made of steel.

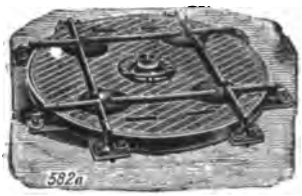


FIG. 76.

The cars designed by Decauville for industrial railways were

built of iron and steel, and in the form known in this country as tip-cars. These consist of an iron truck with steel-flanged wheels of about 18 ins. diameter fixed to axles, which are attached to the frame of the truck by means of box-shaped axles—boxes sometimes provided with springs. At both ends of the truck there are two trusses for the support of the body of the car. These are made of steel and are supported on four pivots, two on each end resting on the trusses and so arranged as to have the center of gravity of the car, when loaded, just a little above the plane of the pivots and between them. Such a construction, while it prevents the overturning of the cars during the hauling, allows them to be easily unloaded by tipping, hence the name of tip-cars. The efforts of any ordinary workman will cause the body of the car to turn over a pair of pivots, and it will assume then

FIG. 77.

the position indicated in Fig. 77, and the material will automatically descend by gravity on account of the peculiar shape of the car. Figs. 77 and 78 represent standing and unloaded tip-cars

for industrial railways as built by G. L. Stuebner of Long Island City, which are very similar to those built by Decauville.

All tip-cars are constructed on the same principle, but with different arrangements for the support of the body of the cars and for unloading; these are covered by patents controlled by the various manufacturers. The capacity of the cars varies from 12 to 45 cu. ft., but cars of 1 cu. yd. capacity are the most convenient for ordinary excavations. The height of the body of the car is so arranged as to require the smallest effort in loading

FIG. 78.

it, and to allow the easy propulsion of the car either by hand or by other motive power. Attached to the frames of the trucks there are bumpers, chains, and hooks in order that several cars may be formed into trains. Some cars must be also provided with hand-brakes which are placed on a small platform on the rear of one of the trusses supporting the body of the car.

Side-dumping tip-cars are most commonly employed, but cars are also constructed which dump at the front and back. These

are similar to the side-dumping cars described above, the only difference being that the frames supporting the body of the car, instead of being placed at the front and rear end of the truck, are located along its two sides. Tip-cars are used for carrying earth or stones, but in case larger stones are to be carried platform cars as indicated in Fig. 79 are found to be more convenient.

The advantage of industrial railways is that they may be operated by any motive power, either animal or mechanical. The total resistance of an ordinary tip-car hauled on a horizontal

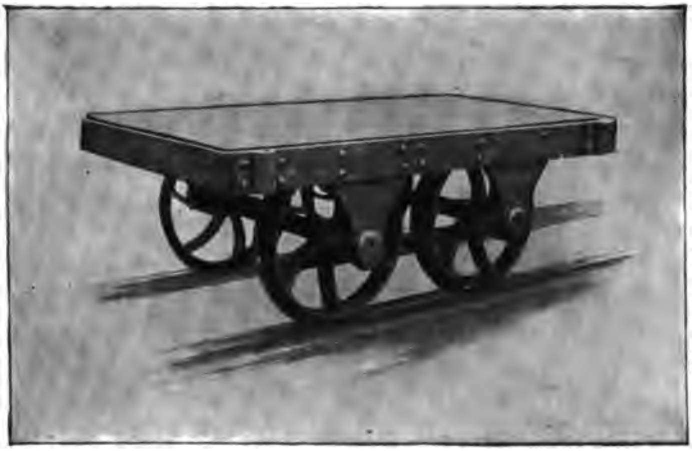


FIG. 79.

road can be assumed at 15 lbs. per ton and the resistance increases in the ratio of 4 lbs. per $\frac{1}{10}$-in. grade per foot. Industrial railways, although laid on horizontal roads, on account of the undulations of the road-bed can be considered as laid on $\frac{1}{2}$-in. grade and then the total resistance of a tip-car will be 35 lbs. per ton. The ordinary capacity of these tip-cars varying between 20 and 45 cu. ft., the total weight of their loads will vary from 2000 to 4500 lbs. and the resistance to traction will therefore vary from 29.16 to 65.6 lbs. Since the weight that any ordinary laborer can support walking 3 ft. per second can be considered as varying from 50 to 60 lbs., it is easily seen that any laborer can move a loaded tip-car, especially if it is not of the largest dimensions.

The working power of a horse is considered as five times greater than that of a man, and consequently a single horse can easily haul a train composed of not less than five tip-cars and even a greater number, according to their capacity. Horses employed as motive power on industrial railways give efficient results for distances not greater than 1 mile; for greater distances, however, the employment of a small locomotive is found to be more economical.

Industrial railways should form an essential part of any contractor's plant. The writer has had the opportunity to employ them several times, and in different countries and under entirely different circumstances they have always given most satisfactory results. From his own experience the writer can certify that industrial railways afford a most economical means of transportation for excavated materials within about 1-mile distances.

In the transportation of excavated materials, narrow-gauge railways are more commonly employed than the industrial railways just described. This is chiefly due to the adaptability of these roads to any locality and all distances and also because the trains may be hauled either by horses or by steam-locomotives. In general, these roads are convenient for the transportation of not less than 20,000 cu. yds. of earth and the trains can be advantageously hauled by horses to a distance of 3000 ft., but for longer distances steam-locomotives will give better results. These limits, however, do not apply to every case, but give in a general way an idea of the limitations of the various methods of hauling. All the particular conditions of the work and locality should be accurately examined before deciding upon the most convenient road and method of hauling to be used.

The road of narrow-gauge railways temporarily built for the transportation of the material consists of light rails of from 16 to 24 lbs. per yard, fixed to the ties by means of iron spikes just as in ordinary railroads. The various sections of rails are made continuous by means of fish-plate joints. According to the traffic and also the cars at hand, the gauge of the track is usually made 2, $2\frac{1}{2}$, or 3 ft. The ties are made of square timbers 6×6 ins.

and 5 ft. long and they are spaced about 2 ft. center to center. The road is provided with curves, switches, turnouts, crossings, etc., just as any ordinary railroad would be.

It is necessary, however, to remark that in earthworks the narrow-gauge road being constructed either on top of the newly built embankment or on the bottom of the pits or trenches is liable to settle under the weight of the traffic, and consequently it will be necessary to have a special gang exclusively employed in maintaining it. The construction of the road is very expensive when compared with industrial railways. As a rule it can be assumed that it will take twenty days' work for a man to build one mile of narrow-gauge road, so that the cost per mile will be $30. At least two men per mile should be employed for repairing, and this will cost $3 per day per mile of road.

As a rule, the cars employed on these roads are self-dumping. The cars can be divided into two groups, according to the manner in which they are dumped, whether on one side or on all sides. Whatever their form may be they are always composed of a four-wheeled truck, upon which rest the various devices supporting the box containing the excavated materials. They are built of different sizes and shapes. One of the simplest forms of dumping-car is the one illustrated in the diagram (Fig. 80). This, as usual,

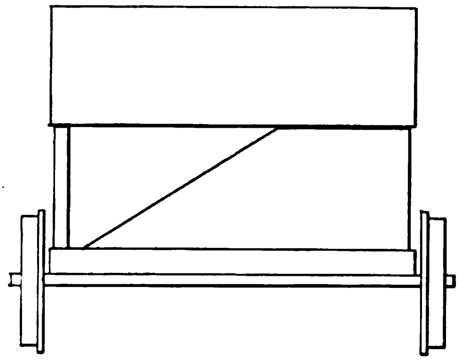


FIG. 80.

is composed of an ordinary four-wheeled truck, upon which rests a wooden frame of trapezoidal shape with the longer side on the

truck and the small one on top supporting the body of the car. This is hinged to the frame and when loaded is kept in place by means of vertical props resting on the truck and holding the edge of the box which does not rest on the wooden frame. When the car is loaded the center of gravity remains very close to the line of the edge of the trapezoidal wooden frame, so that after the vertical supports have been removed, a laborer with a very small effort will turn the body of the car around the hinged axis

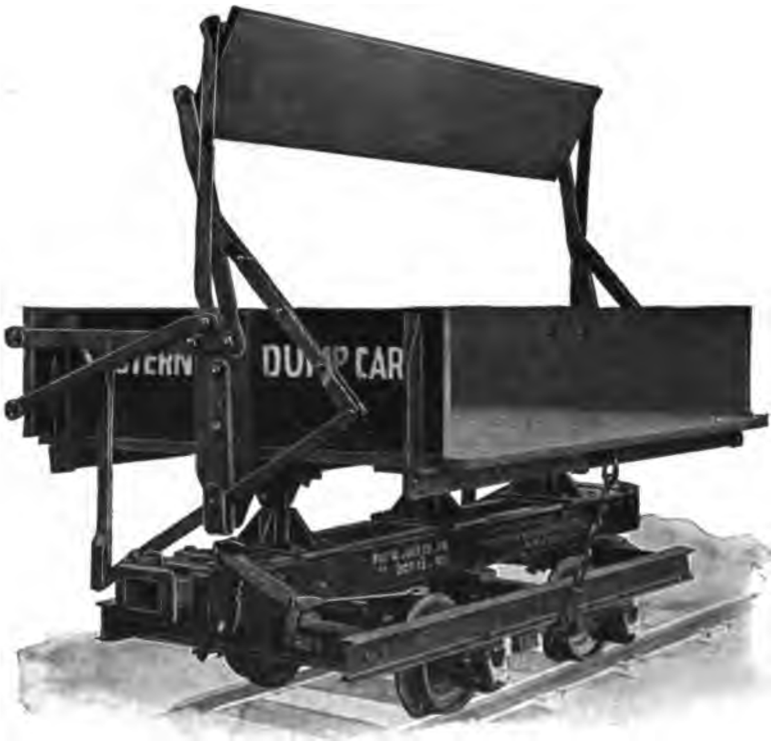


FIG. 81.

and the box will take a position following the sloping side of the trapezium. If the board along the side of the car has been previously removed, the earth will fall to the ground.

On the same principle is constructed the Western Dump-car

illustrated in Fig. 81, which has the great advantage over the one just described that it can be dumped on either side. In this case also the car is composed of a four-wheeled truck provided with an additional longitudinal centerpiece upon which rest the cast-iron stands supporting the body of the car. As is clearly shown in the figure, these stands are pin-connected so that the car may revolve on either side. The box is kept horizontal by means of chains tying it to the truck. By loosing one of the chains and with a very small effort any laborer can easily tilt the car, which will overturn in the opposite direction, thus unloading the material. The chain fastenings can be released by the foot and the car dumped while in motion. The sideboards of these cars work automatically, opening on the side on which the dumping is done and closing as soon as the car is returned to an upright position. These cars are built of different sizes, from $1\frac{1}{4}$ cu. yds. to 5 cu. yds. capacity. Another type of dumping-cars used in connection with narrow-gauge railway are rotary dumping-cars, which may unload the material not only on both sides like those just described, but also in front and back. Such an arrangement is very convenient for building embankments in

FIG. 82.

which the cars must be unloaded at the front of the slope. There is a large variety of these cars, and all of them are constructed on the same principle. In the center of a four-wheeled truck there is a circular iron platform to which is pivoted another similar one attached to the bottom of the body of the car, so that it may revolve around its center. If the car is provided with a

dumping arrangement, it can be unloaded in any position. Fig. 82 shows the Western Rotary Dump-car. This is provided with a pivoted or swinging draw-bar, which is pushed aside when dumping over the end, so that a much steeper angle is made in dumping than if it were necessary to dump over the draw-bar. The same automatic device for the end-board is used on the rotary car as is used on cars dumping sideways.

All dumping-cars, whatever their form may be, are usually hauled in trains. They must be provided with bumpers and chains and other connections similar to but simpler and of smaller dimensions than are used in ordinary railroad cars.

The motive power used in hauling the trains is either horses or steam-locomotives. Having discussed traction by horses in other parts of this book, it will be proper to devote here a few words to locomotives. These are specially constructed for this kind of work, are very light, and economical both in cost and in running expenses, and are constructed of different shapes by various manufacturers.

Fig. 83 shows a four-coupled locomotive built by the Baldwin Locomotive Works of Philadelphia, Pa., for the Colorado Fuel and

FIG. 83.

Iron Company. It was built to run on a 3-ft. gauge and its total weight was 20 tons. Its principal dimensions were: Diameter of cylinder, 12 ins.; length of stroke, 16 ins.; distance between driving-wheels, 5 ft.

The quantity of coal consumed varies with the locomotive; on the average it may be assumed that it consumes about 6 lbs. of coal per horse-power per hour. The quantity of water about gallons per mile. The tractive power of a locomotive, according to Trautwine, is given by the following formula:

$$T=\frac{\begin{array}{c}\text{Square of diameter of}\\ \text{one piston in inches}\end{array}\times\begin{array}{c}\text{Single length of}\\ \text{strokes in ins.}\end{array}\times\begin{array}{c}\text{Average steam pres-}\\ \text{sure in the cylinders}\\ \text{in lbs. per sq. inch}\end{array}}{\text{Diameter of driving-wheel in inches}}$$

The cost of hauling 1 cu. yd. of earth by means of steam-locomotives is given by dividing the daily running expenses by the total quantity of the hauled materials. The daily running expenses are given by the consumption of coal, water, and lubricants, and the wages of the engineer in charge of the locomotive. Coal and water vary with the distance run, while the wages of the engineer remain fixed. Assuming that a locomotive will travel 100 miles per day carrying 1000 cu. yds. of earth to the dumping place, the cost of hauling a unit of volume will be as follows:

Coal........................	$4.00
Water.......................	1.00
Oil, etc.....................	.80
Engineer....................	3.50

$$\frac{\text{Total daily expenses...... }\$9.30}{\text{Quantity of earth hauled in a day.. }1000}=0.009\text{ ct. per cu. yd.,}$$

or nearly 1 cent per cubic yard. Other items should be added that will greatly increase the cost of hauling the unit of volume of the material. These are, for instance, the wages of the laborers employed in repairing the road, the interest of the invested capital, the repairs to locomotive and cars, which is not a small item, the sinking fund, and the superintendence.

When a very large quantity of material has to be excavated in a short time, and the distance to where the materials are to be deposited is large, it will be more convenient to employ loco-

motives of greater efficiency running on standard-gauge tracks. In such cases the excavation is made by several powerful machines, and they must be served by a continuous procession of cars of large capacity. The trains are formed of several cars heavily loaded, and consequently it is necessary to use a tractive force of great efficiency.

The standard-gauge road is built with rails and ties of the same dimensions used in ordinary railroads, and is constructed in the same way. In case the work will not last for many years, it will be more convenient to employ second-hand material both for the rails and ties instead of buying new. It will cost a great deal of money to keep the track in working order, since the weight of the locomotives and loaded cars will tend to sink the track, especially if located on top of recently constructed embankments or in the bottom of the open trenches. This is an important item that will greatly increase the cost of hauling, and it should not be forgotten.

The locomotives employed are of the railroad type, either with water-tank and fuel-bunker mounted on the locomotive, or carried by a separate tender as on ordinary railroads. Since heavy locomotives are very expensive, it will be perhaps convenient to get some of those discarded by railroads for ordinary traffic. But the advantage of using second-hand material will depend upon the amount of the earth to be hauled, the magnitude of the work, and the time in which the work is to be completed. Locomotives, as a rule, are discarded by the railroad companies when the yearly expenses for repairing required to keep them in working order are very heavy. In such a case, and especially when the work will last for several years, it will not be convenient to get discarded locomotives, but to use new ones of lighter efficiency.

The cars used in the excavation are of three different types—the platform, the gondola, and the dumping cars. Platform cars are the simplest and the most commonly employed cars for hauling earth excavated by machines. They are 34 ft. long and 7 ft. wide, and when loaded they contain almost 10 cu. yds. of earth.

They consist of a heavy platform of hard wood supported on a double four-wheeled truck. Around the edges of the long sides of the platform there are iron eyes to receive short vertical posts which guide the unloading apparatus. At one end the cars are provided with a hinged apron made of sheet steel as wide as the whole width of the car, and of such a length as to abut on the next car, thus bridging the empty space between the two consecutive cars, and allowing a continuous support to the unloader, whose description is given on p. 326.

The other type of car used to haul excavated earth is the ordinary gondola car. This is similar both in construction and dimensions to the platform car, with the difference that all around the edges there is a 3-ft.-high strong board to retain the materials. It is very convenient for the transportation of materials to a great distance, since each car may transport over 25 cu. yds. of material at a time. But it must be unloaded by hand, and this is an expensive item to be added to the unit of cost of the material. The relative convenience of employing the gondola instead of the platform cars is obtained by an accurate comparison of all the items of cost in both cases; the greater number of cars and locomotives but the inexpensive unloading in one case *versus* the smaller number of cars and locomotives together with the costly unloading in the other case.

The other type of car used in the transportation of excavated material is the dumping-car. There is a large variety of them on the market, all covered by patents, which the manufacturers claim afford great advantages. Those, however, used by contractors are only of two kinds—one with a very limited usefulness, while the other car is growing in favor because it can unload the material where it is needed. The simplest dumping-car is the one used by railroads for carrying coal. It is mounted on a double four-wheel truck, and is in the shape of a trough with the interior sloping down toward the bottom, where it is provided with a trap-door. By opening this the material will descend by gravity and the car be unloaded. These cars, however, discharge their contents between the track, and they can be employed only when

the dumping is effected on trestles, otherwise the material deposited within the rails will obstruct the traffic of the road. Consequently their utility is very small, and it will not be advisable for the contractors to use them except in the case of dumping from trestles and when the rolling stock may be provided or loaned by the railroad company.

More convenient are the Goodwin dump-cars, illustrated in Fig. 84. Notwithstanding that these have been introduced only

FIG. 84.

a few years, they have met with the greatest success, and are already extensively used by contractors, railroads, and mining companies. They are constructed entirely of steel, and are divided into two compartments which can be unloaded separately, the division being made by a steel diaphragm. The advantages of these cars are given by the manufacturers as follows: (1) That, on account of their peculiar construction, they discharge all kinds of material hauled as freight, using the gravity of the material alone as the unloading power. (2) That the discharging apparatus can be released by compressed air, steam, electricity, or hand-power at will. (3) That they can be discharged on either

or both sides, or in the center, according to the different manners indicated in the diagram (Fig. 85), and yet without careening or moving of the body of the car. (4) That a train of Goodwin cars or one car can be discharged with perfect safety while running at

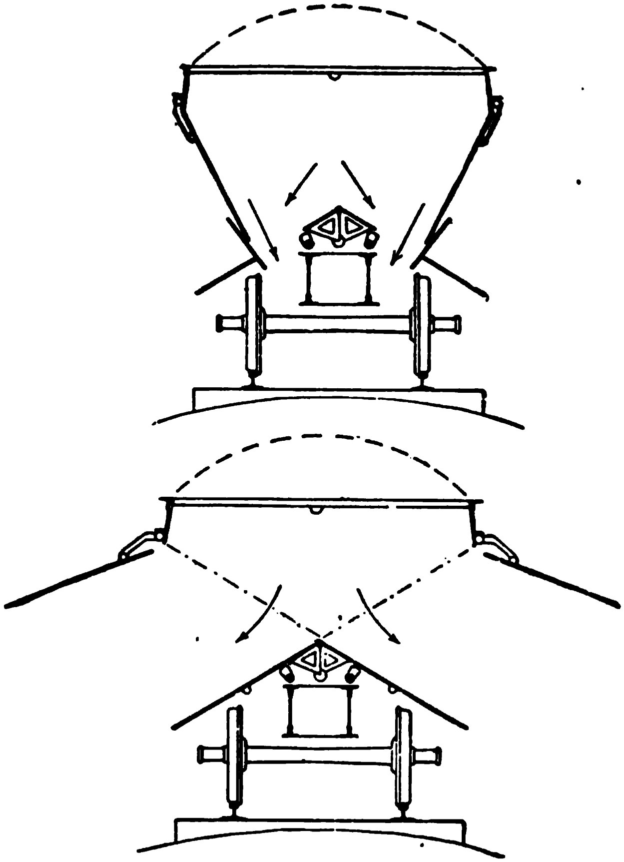


FIG. 85.

any speed, and the valves (floor) need not be replaced until the car reaches the loading station. (5) If the cars are discharged while running, they will spread the load from 5 to 30 ft. from the track; the width of "spread" being regulated by the speed of the train. (6) That one man in any part of the train can discharge the loads from all or any number of cars in the train simultaneously.

CHAPTER XIII.

METHODS OF HAULING EXCAVATED MATERIALS ON INCLINED ROADS.

THE methods of hauling excavated materials, so far described, can be employed only on roads with a grade less than 8 or 10 per cent. when wheelbarrows, carts, wagons, and scrapers are used, or on roads whose inclination is not greater than 3 per cent. when the materials are hauled on cars running on tracks. But in many cases, on account of configuration of the ground, and especially in carrying earth from borrow-pits to the embankment, it will be almost impossible to develop roads with such a small gradient, and then engineers and contractors must provide inclined roads.

A primary division of the various means of hauling materials by means of inclined roads can be made according to whether the materials are hauled up or down grade. The devices for hauling materials up grade are so many and of such different shapes that it is very difficult to give the details of each one, and here, therefore, only the most important will be described to illustrate the principles upon which they are constructed. The Chicago Drainage Canal was a work of great magnitude in which all the materials excavated on the bottom of the canal were raised up and deposited on the spoil-banks along the edges, and many different methods of hauling the materials up inclines were employed by the contractors. The details of these machines are found in Chas. S. Hill's book, *The Chicago Main Drainage Channel*, published by the Engineering News Publishing Co., which can be advantageously consulted for more information. To haul materials down steep inclines is a much simpler affair, and it is usually done by means of gravity roads.

Inclines for Wheelbarrows.—When the hauling is done by means of wheelbarrows and the earth from the bottom of a borrow-pit must be raised to the top of an embankment under such conditions that no road can be stretched between these points, the simplest manner of overcoming the difference of level is by means of tied barrows. This consists in hauling the materials on wheelbarrows passing over a plank road inclined according to the slope of the cut, and just wide enough to allow the passage of two wheelbarrows in opposite directions. A rope is placed along one side of the plank road and, passing through a horizontal sheave at the top of the incline, returns on the other edge of the plank road. At each end of the rope is attached a wheelbarrow. The laborer descending with the empty barrow will assist the ascent of the other man, who is pushing the loaded barrow up the incline.

When the inclination of the slope is greater and consequently too much effort will be required to push the wheelbarrow up the plank road, animal power may be advantageously employed. In such a case, at a convenient distance from the edge of the slope is placed a vertical post (Fig. 86) provided with two sheaves. A

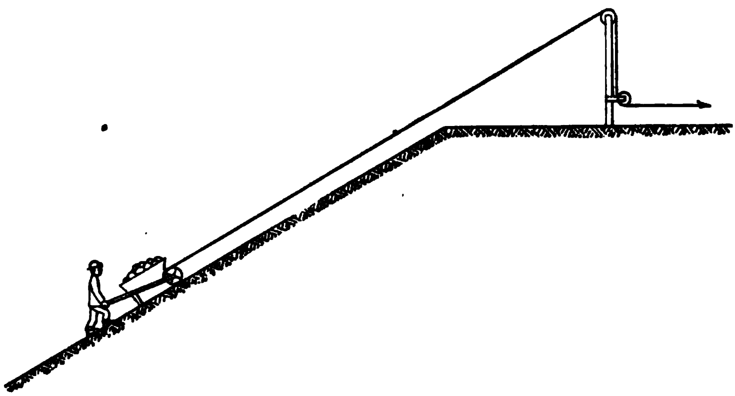


FIG. 86.

rope with one end attached to a wheelbarrow in the bottom of the excavation passes over the upper sheave and assumes a horizontal position by passing around the lower sheave. At the other end of the rope a horse is hitched, and in moving pulls the

rope, thus causing the ascent of the wheelbarrow up the plank road. It is convenient to build the incline higher than the top of the slope, and ending with a platform under which may pass a car or wagon into which the excavated materials are dumped. Fig. 86 clearly indicates this manner of hauling materials up inclines. It was employed in the construction of the London & Birmingham Railway; on some branches of the Paris, Lyon & Mediterranean Railway in France, and more recently on the St. Gothard line.

The work done by means of wheelbarrows is, as a rule, slow and expensive, and, on account of the great improvement in hoisting-machines in the last few years, this simple method of hauling excavated materials up the inclines is very seldom employed. But in some particular cases, as, for instance, when along the line of the road there is a small isolated embankment to be constructed from the material excavated in a borrow-pit, this slow and ancient method may still be found convenient.

Inclines for Carts and Wagons.—To overcome the sharp difference of level existing between the ground-surface and the bottom of the excavation, when the earth is removed by carts and wagons, inclines are made of earth left in place. Another team of horses hitched to the shafts of the carts will facilitate the moving of the vehicles up the incline. When the remainder of the excavation is completed these inclines are removed by cutting them down until they become so sharp that vehicles cannot pass, and then they are cut and removed by hand, working in benches, until the vertical side of the excavation is obtained. This manner of hauling excavated materials is commonly employed by cellar-diggers in every city.

When the work of excavation is of such importance that many cars have to be hauled every day, and when the length of the haul is so great that more than one team has to be employed in helping the carts surmount the incline, hauling the carts by steam-power will be found more convenient. In such a case a single-drum reversible engine with a wire rope coiled around the drum will be placed on top of the incline. The end of the rope is pro-

vided with a hook which engages the ring at the head of the shaft of the wagon standing at the foot of the incline. By turning the engine the wire rope will coil around the drum, thus pulling up the incline the carts and wagons together with the horses, which will walk easily, being relieved of the load. An empty car going down the incline will carry the rope to the bottom of the excavation, so as to be attached to a loaded cart. By this method the writer has seen from 12 to 15 cars per hour hauled up an incline 100 ft. long and 20 ft. high; for ordinary calculations it can be assumed that one car every five minutes, or 12 per hour, can be hauled, making an average of 100 carts per day.

When the excavated materials are removed by means of tip-cars hauled by horses and running on light, narrow-gauge tracks, the difference of level between the bottom of the excavation and the top of the embankment is usually overcome by means of plank roads similar to those employed in connection with wheelbarrows. In such a case, however, two plank roads are built parallel to each other, and at some distance apart, and are provided with tracks similar to those employed throughout the work. A rope is stretched along the plank roads and it assumes the horizontal position on top of the incline and in the space between the two roads by passing through sheaves placed horizontally. To the horizontal portion of the rope is hitched a horse which by moving in one direction causes the ascent of a tip-car tied to one end of the rope and the descent of another car tied to the other extreme. This operation is reversed when the horses move in the opposite direction.

This manner of hauling is not the most economical, but it can be usefully employed in certain special cases, as, for instance, when all the hauling is done by means of cars moved by horses on a temporary narrow-gauge road and the embankment built with materials taken from borrow-pits is not very large; when the work is done in localities in which labor is cheap, or when the work is so located that the economy obtained from the employment of mechanical power will not compensate the expense of transporting and setting up a mechanical plant.

The quantity of materials hauled in this manner varies from 60 to 75 cu. yds. per day. For such an output two horses and drivers and four laborers, one at each end of the inclined roads, are required. If $5 be the daily cost of hiring the two horses and their drivers, and $5 is paid the laborers, the cost of hauling 1 cu. yd. of material will vary between 14 and 18 cents.

Animal power is not advantageous when the quantity of the earth to be raised is large and when the capacity of the cars is not less than 1 cu. yd. In such cases it will be necessary to use steam-power. The simplest way of hauling cars by steam is to build an inclined road supporting trucks connected with those at the top of the embankment and at the bottom of the excavation. At a convenient distance from the top of the incline is located a single-drum reversible hoisting-engine. The hoisting rope coiled around the drum is provided with a hook at its free end. At the lower end of the incline a train is formed by uniting together 3, 4, or 5 cars, and the hook of the hoisting rope is fastened to the first car. By putting the engine into gear, the cable will coil around the drum, thus causing the cars to ascend the incline. Reaching the top of the embankment the cars are shifted onto the spoil-tracks and the materials dumped in the required place. The descent of the empty cars is accomplished in exactly the same way; a train is formed and to the rear end of the last car is attached the hook of the cable. The engine is then reversed and, on loosing, the cable will lower the cars down the incline, thus preventing their rushing down at great speed.

This manner of hauling is very commonly employed in works of any magnitude. It was employed on some sections of the Chicago Drainage Canal, where full trains were hauled at once to the spoil-banks, and, more recently, it has been used on Section 13 of the New York rapid-transit road to haul to the surface the materials excavated in the tunnel north of 157th Street along Broadway; there, however, only one car at a time was hauled, a curve being provided at the top of the incline where the cars were shifted and side-tracked until a train was formed and hauled to the dumping place by a dummy-engine.

The efficiency of this method of hauling depends upon the length and grade of the inclines. In general it can be said that from 500 to 600 cu. yds. of material can be hauled up in a day of ten working hours.

Hauling by Endless Chain. — Another method of hauling loaded cars up inclines is by means of an endless chain or wire rope. The incline is built wide enough to contain a double-track line, one track being used for the ascending cars and the other track for the descending cars. When the endless chain is used this passes in the center of the tracks and at the two ends of the inclines revolves around a drum provided with a gear whose teeth grasp the links of the chain. If one of the drums be moved by horse, steam, or other motive power, it will cause the chain to travel continuously along the inclines, and the cars attached to the chain will ascend one of the inclines and descend the other. When instead of a chain an endless rope is used, no gears are required, but the rope is wound two or three times around the lower drum so as to cause friction, and at the other end of the incline it is coiled around a fly-wheel moved by a steam-engine. To ~~prevent~~ friction of the chain or rope in its travel along the inclines it is supported by sheaves placed a few feet apart and between the rails of each track.

The attachment of the cars to the endless chain can be very simply made, consisting only of an iron bar passing through the front bumper of the car and fitting inside the link of the chain. When the car has reached the upper end of the incline, the iron bar is lifted and the connection with the driving-chain discontinued. A better and safer manner of connecting the cars with the chain or wire rope is to provide the driving-chain or rope with buttons, which can be made of steel wires placed every 20, 25, or 30 ft. apart. At the front of the car there is a bar ending with an inverted U. This is made in such a manner that it allows the passage of the chain but not the buttons; these will hold fast the cars and draw them up the incline. By raising this fork the connection with the driving chain or rope is discontinued and the car may be switched to the tracks leading to the dumping

place. Another way of connecting the cars to the driving cable is by means of a grip. Such an expensive arrangement may be found useful, perhaps, in continuous works, as in mines, but not in temporary works such as earthwork excavation, and any further description will be omitted.

This manner of hauling cars on steep roads is very seldom employed by engineers and contractors in every-day works of excavation. It may be, however, found convenient when a very large quantity of material has to be hauled and conveyed to the spoil-banks within a very short time. In such a case the conditions of the work will require the use of many tracks radiating from the ends of the inclines to the various points of the excavation and dumping grounds.

The average velocity of the driving chain or rope is about 5 ft. per second, and since the cars may follow each other safely at a distance of 60 ft. apart, the efficiency of the apparatus will be 5 cars per minute or 3000 cars per day. In practical work it can be assumed at 1000 cars of 1 cu. yd. capacity and consequently at about 1000 cu. yds. per day.

Hauling by Traveling-cars.—The cars hauled up inclines in the various ways described are the usual dumping-cars employed for hauling purposes moving on narrow-gauge tracks on horizontal roads. They have been employed even on slopes of 1 to 1, with a velocity of 5 ft. per minute. But with greater velocity and steeper slopes they can be easily overturned, thus causing a long delay in the traffic and serious trouble. Then instead of attaching the cars directly to the hauling cable, it is more convenient to place them horizontally on a platform of a specially constructed car, which is hauled up the incline by means of a cable coiled around the drum of a reversible hoisting-engine.

This special car, illustrated in Fig. 87, consists of a simple truck in which the front and rear wheels are at different levels. The platform of the car is horizontal, so that its sides are triangular in form, and is provided with tracks of the same gauge used throughout the work, or with a turntable when the material to be hauled converges from different lines and

must be discharged at various points. The incline is built lower than the plan of the excavation, in order that the tracks on the platform of the car may be flush with those on the floor of the

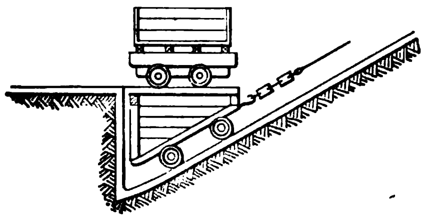


FIG. 87.

excavation. The upper end of the incline will also be lower than the plane of the rails leading to the spoil-banks.

This method is found convenient when large cars are used for hauling purposes, and it is employed also in slopes of smaller inclination than those indicated above.

Gravity Roads.—So far only the cases in which the excavated materials have to be raised from the bottom of a pit or trench up to the embankment or ground-surface have been considered; but there are also cases in which the materials in order to reach the waste-banks must descend an inclined road. This is accomplished by means of gravity roads in which the loaded cars descending by their own weight on an inclined road haul up the empty ones. The essential parts of gravity roads are chain or wire rope to which the cars are attached and a drum provided with a brake to regulate the speed of the cars. Around this drum is coiled a portion of the driving rope. The attachment forming the connection between the rope and the cars may be of any of the designs described already for inclines employed in hauling up materials.

A gravity road commanded by an endless chain was employed at the Modane portal of the Mont Cenis tunnel in order to carry to the spoil-banks the materials excavated from the front. This consisted as usual of two parallel tracks laid on an incline. In the middle of the tracks was laid a chain encircling a driving drum at the top of the incline and another returning drum at the foot of the incline. Along the incline the running

of the chain was facilitated by means of rollers placed between the tracks. The drums were provided with teeth engaging the links of the chain.

Gravity roads operated by wire ropes were used on Section 13 of the rapid-transit railway, where the earth excavated from the trenches along Broadway was carried down to a place near the Hudson River to form the embankment for the extension of the Riverside Drive to Lafayette Boulevard. Various methods were employed for carrying down the excavated materials, but

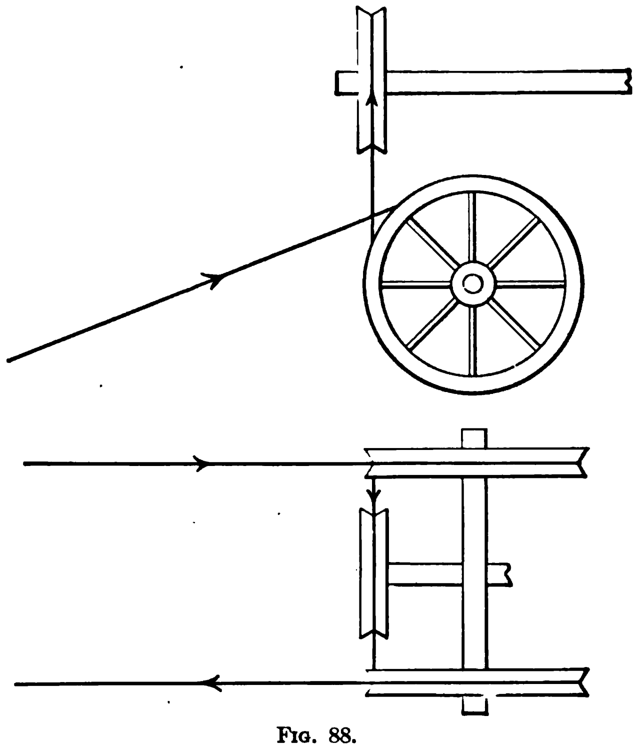


FIG. 88.

a gravity road for hauling down the materials loaded into the ordinary Western dumping-cars was built at 144th Street. This consisted of a double-track line of 3 ft. gauge placed along the incline and connected with switches and curves to the line running along

Broadway and parallel to the cut. The device for regulating the descent of the cars was located about 30 ft. from the incline. It consisted (Fig. 88) of two grooved wheels 4 ft. in diameter and 5 ft. apart, placed longitudinally and with the axis at the level of the ground. The wheels had flanges surrounded by wooden brakes similar to those employed in hoisting-engines; the brakes were commanded by handles located above a platform in a small frame building where the operator stood, and where from a large window he could command a view of the whole incline. In front of this frame building was another grooved wheel 3 ft. in diameter, placed transversely and higher than the two others. A wire rope was attached to the descending car, passed over, and was wound around one of the longitudinal wheels, then from underneath the first wheel passed over the wheel placed transversely and from this underneath and over the second longitudinal wheel and was attached to the empty car at the foot of the incline. In this manner the descent of the loaded car was regulated by the operator. The road worked in the most satisfactory way and without any accident. Only two rollers were placed between the tracks at the top of the incline, but these were insufficient since the rope made grooves in the ties over 1 in. deep.

Belt Conveyors. — Another method of conveying excavated materials up inclines is by means of belt conveyors. These consist in depositing the materials upon an endless belt, which in traveling carries them to a higher distant point. The belt may travel horizontally, but as a rule it moves in an inclined direction, and is more commonly employed in carrying materials up to higher points. In the description of the New Era grader a belt conveyor was used for loading the cars and formed an essential part of the machine.

A belt conveyor is made up of several parts—the belt, the runners, and the driving drum. The belt must be of such material and construction as not to be easily worn out by the materials that it carries; the runners must be built so as to be perfectly isolated from the particles of the carried material, otherwise they will be clogged, thus preventing the running of the belt;

the driving drum, which is usually placed at the bottom of the incline, can be driven in different ways according to the length of the conveyors. Small and short conveyors can be directly driven from line shafting. In larger and longer conveyors the driving drum can be driven by belt from line shafting running at moderate speed, which is further reduced by large driven pulleys on a head shaft, or it can be directly driven by a system of cog-wheels.

Since the belt of these conveyors runs continuously they give the most efficient work in carrying away materials excavated by means of machines working continuously. In a paper read before the American Society of Civil Engineers, July 2, 1888, Mr. William Plumb Williams thus described a belt conveyor used in connection with a down-digging machine in the construction of the Panama Canal:

"At Tavanilla in connection with the endless chain of bucket excavator was employed a transporter. A truss of 500 ft. in length was supported at one end on the deck of the excavator and extended at right angles to the fore-and-aft line of work, the other end being supported upon a traveling derrick and car. This truss was 6 ft. in width and 10 ft. in height, and an endless belt 4½ ft. wide received motion from an independent engine of the excavator. The contents of the buckets of the excavator were discharged into the hopper and out on to this traveling belt, thence along over top of truss until the end was reached, when, the belt going over the outer tumbler, its contents fell to the ground. The outer end of the truss may be raised as high as 30 ft. from the ground, giving room for a large bank to fall without obstructing the passage of derrick car from the débris sliding toward the machine.

"In this work the excavator was digging 30 ft. below the rail of the car; material was carried 500 ft. distant and elevated a total of 50 ft. This necessitated the keeping up of three tracks—of excavator, a track of platform car supporting belt, engine, and boiler, and a track of derrick car. In addition to the regular crew of the excavator, there were used one man on

the derrick car to preserve a constant forward motion up the track with the excavator, one engineer on the platform car to regulate belt engine, and one fireman each on derrick car and platform car."

Belt conveyors were also employed in hauling the materials excavated from the bottom of the canal to the waste banks in the construction of the Chicago Drainage Canal, and were designed by Mr. L. W. Bates of Chicago. These consisted of an endless rubber belt 22 ins. wide, passing from a driving station on one bank of the canal across to the other side, along a truss over the spoil-bank round suitable pulleys at the further end of the truss and back again to the power station on the opposite bank. The installation on each side was mounted on tracks, so that it could be advanced as the work progressed. The belt was kept loaded by a steam-shovel with a granulating attachment, into which the earth was delivered and reduced to a suitable condition before being discharged upon the belt. The delivery capacity varied from 300 to 800 cu. yds. per ten-hour shift, not a high duty. A writer in *Engineering* commented on the extensive character of the plant and the costly labor, since it required a total force of 135, about half of whom were skilled woikmen paid from $2 to $3 a day. In bad weather it was found that the belt did not serve the purpose of conveying efficiently, and only under favorable conditions could the excavating and granulating machinery be worked to the full capacity.

In the last few years another belt conveyor has been placed on the market, and has found a very considerable employment in public works, and its use is daily extending. It is the Robins belt conveyor controlled by the Robins Conveying Belt Company of New York. The Robins, like other belt conveyors, is composed of the three essential parts—the endless belt, the runners, and the driving drums at the end of the incline. The belt is made of canvas covered with layers of rubber thicker at the center than at the sides, thus protecting the belt against the abrasion of the material that travels upon it. The runners, or idlers, as they are called, are composed of three cast-iron cylinders arranged in such

a manner so as to form a trough, thus preventing the materials traveling on the belt from fulling on the sides and clogging the runners. Fig. 89 shows the arrangement of the trough idlers in

FIG. 89.

the Robins conveyor, and also the runners below to facilitate the return of the belt. When carrying wet and muddy material, which easily sticks to the belt, this conveyor is provided with a brush underneath the driving drum at the top of the incline which cleans the belt of any material that may remain attached to it.

The Robins belt conveyor was used by Messrs. Ryan & Parker in excavating for the foundations of the new 120,000-H.P. power-house of the New York Gas and Electric Light, Heat, and Power Company at Thirty-eighth Street and East River, New York. This plant covers an entire city block. The work was done during very cold weather, being commenced in December, 1899, and finished in January, 1900. An open trench 7 ft. deep was dug, running through the center of the lot. In this the conveyor was installed. Across this trench three bridges were laid with a hole about 3 ft. square in the center of each, with chutes leading from these holes to the conveyor. A large number of wheel scrapers constantly passing over these bridges dumped their loads into the holes. The material fell onto the belt which carried it away, running level for the greater part of its length but taking a vertical curve of about 100 ft. radius as it approached the river until

a height of 20 ft. was attained. At this point it delivered the material into a large barge, which when filled was towed out to sea and dumped. The conveyor was driven at its head end by a small horizontal engine, very little power being required. It was subjected to the roughest kind of usage, rocks weighing over 100 lbs. being constantly dumped upon it, but it never caused a

FIG. 89a.

moment's stoppage during the entire work. The width of the belt was 30 ins. and the actual quantity of material removed exceeded 1200 cu. yds. per day. The work was so satisfactory that the contractors declare that they will make use of the Robins belt conveyor in any excavating which they meet with, provided of course that the conditions are suitable.

CHAPTER XIV.

VERTICAL HAULING OR HOISTING OF EXCAVATED MATERIALS.

A DIFFERENT method of hauling materials is employed when the horizontal distance between the cut and fill is very small, while the vertical distance is great, or when a great difference of level must be overcome in order to send the excavated materials to the fills, or spoil-banks. In such a case it is very difficult to construct inclines, and it is preferable to hoist or raise the materials either directly or indirectly in a vertical direction. It is termed direct hoisting when the buckets containing the materials are attached directly to the hoisting-cable of the machines, and it is termed indirect hoisting when the cable is attached to a platform or some other device upon which are placed the cars containing the excavated materials. Again, either direct or indirect hoisting can be done by machines which simply raise the materials in a vertical direction; but direct hoisting can be also done by machines which not only raise the materials in a vertical direction, but transfer them horizontally. The principal hoisting-machines are the windlass, horse-gin, and elevators, while those which both hoist and transfer the materials are cranes and derricks.

Windlass.—The simplest and oldest hoisting-machine is the windlass. This consists of a horizontal wooden drum about 2 ft. in diameter, its axis usually formed of an iron rod which is produced and bent so as to form a crank at each end of the drum. In some cases the drum ends with one or two large wheels furnished with iron handles. The drum is ordinarily made up of three wooden circles. Nailed around their circumferences there are hard-wood staves, which can be either close together or a little

apart. The drum is supported by two vertical trusses. Around the drum is wound the hoisting-rope, which has its two ends free. To these ends are attached the buckets containing the material. The rope should be longer than twice the depth at which the materials are excavated, because it is wound three or four times around the drum. The windlass is operated by two laborers, who turn the cranks or the wheels. To obtain the greatest efficiency from the windlass it is necessary to have the axis of the drum a little higher than half the height of an ordinary man, so that the handle of the wheel in its higher position will reach about to the shoulder of the operator; it is also necessary to have at the ends of the rope two buckets of equal capacity. The windlass is placed directly above the shaft.

Windlasses are very seldom employed to-day except in cases where a small quantity of material is to be removed from a small depth, and the work of excavation proceeds very slow, as is the case in the excavation of small piers. As a rule it is admitted that windlasses are suitable for hoisting materials from a depth not greater than 30 ft. and when the total quantity of the material does not exceed 300 cu. yds.

The windlass is operated by two workmen, and the cost of hoisting a unit of volume of material varies with the weight of the material and the depth of the hoist. The cost of hoisting 1 cu. yd. of various materials from different depths is given in the following table; the prices are calculated on a basis of $1.50 per day of ten hours.

Depth.	Materials.			
	Common Loam (76 Lbs. per Cubic Foot).	Sand and Gravel (98 Lbs. per Cubic Foot).	Clay (120 Lbs. per Cubic Foot).	Rock (170 Lbs. per Cubic Foot).
From 10 to	0.14	0.18	0.22	0.31
" 20 "	0.185	0.24	0.29	0.42
" 30 "	0.28	0.36	0.44	0.62
" 40 "	0.37	0.48	0.58	0.84
" 50 "	0.46	0.60	0.90	1.04
" 100 "	0.80	1.02	1.26	1.80

Horse-gin.—The horse-gin consists of a vertical shaft provided with a drum at its top, around which is wound the hoisting-rope. Two or four arms, depending upon the number of horses employed as motive power, are connected to the vertical shaft, which is called the drum shaft. The horses are hitched to the arms. The connection of the arms with the drum is made by means of forks which allow traction in opposite directions. The drum shaft ends with an iron pivot at each extremity, the lower one turning in a bell-metal cup and the upper one in a collar, which is usually in the middle of a beam longer than the arms and fixed to the ground by inclined props. The beam and inclined props form the structure which supports the shaft and consequently the drum. The drum carrying the rope is divided into two parts by a fillet, thus separating the ascending from the descending rope, and it is furnished with horns projecting from top and bottom so as to prevent the rope from working off. The horse-gin is not, like the windlass, placed directly above but at one side of the hoisting-place. The hoisting-rope is wound around the drum in a horizontal position, but assumes a vertical direction inside the shaft. This is obtained by passing it over a sheave placed on a truss just above the pit. The radius of the drum should be proportional to the length of the arm, the most favorable ratio being 1 to 4.

The power of the horse-gin is, of course, much greater than that of a windlass operated by hand, buckets of 1 cu. yd. capacity being commonly used. According to Mr. Lanino, who used horse-gins extensively in connection with the construction of several tunnels on the Napoli Foggia Railroad across the Apennines Mountains, horse-gins are no longer economical hoisting-machines when $V(H+20)>5000$, where V equals the volume of the material to be hoisted and H equals the height of the hoist, the weight of the excavated material being 2100 lbs. per cu. yd. As a general rule, however, it is assumed that it is not economical to employ horse-gins with a depth of hoist exceeding 150 ft. In the following tables are given the cost of hoisting 1 cu. yd. of

different materials from various depths by means of horse-gins operated by one and two horses respectively:

HORSE-GIN OPERATED BY ONE HORSE.

Height.	Common Loam (76 Lbs. per Cubic Foot).	Sand and Gravel (98 Lbs. per Cubic Foot).	Clay (120 Lbs. per Cubic Foot).	Rock (170 Lbs. per Cubic Foot).
50	0.14	0.19	0.215	0.32
100	0.16	0.22	0.27	0.40
150	0.20	0.245	0.32	0.44
200	0.22	0.27	0.36	0.49
300	0.27	0.32	0.42	0.59

HORSE-GIN OPERATED BY TWO HORSES.

50	0.113	0.146	0.184	0.259
100	0.135	0.185	0.210	0.315
150	0.155	0.215	0.265	0.395
200	.....	......	......	......
300	.....	......	......	......

Elevators.—Where large quantities of materials are to be hoisted rapidly, it is generally considered preferable to employ elevators instead of hoisting the skips directly. Besides, the loads carried by elevators are much greater than those carried in a single skip by other machines.

The elevator consists of a car made up of an open-framework box of timber and iron, having a plank floor on which car-tracks can be laid, and its roof arranged for connecting the hoisting-cable. Rigid construction is necessary to resist the hoisting strains. The sides of the car are usually designed to slide against timber guides or on ropes placed against the shaft walls. Some form of safety device, of which there are several, is employed to prevent the fall of the elevator, in case the hoisting-rope breaks or some mishap occurs to the hoisting machinery which endangers the fall of the car. The car is hoisted by means of a wire hoisting-rope of usual construction and dimensions, and able to safely resist the weight. The hoisting-rope, by means of sheaves located at convenient places, passes over and around the drum of a hoisting-engine, which must be reversible. Elevators may be also moved by

horses, and this kind of machine is constructed by the American Hoist and Derrick Company of St. Paul, Minn. Fig. 90 illustrates the elevator-car provided with tracks as built by the Lidgerwood Manufacturing Company of New York.

The plant required for elevators is more extensive and costly than the one required for other hoisting-machines, hence they are employed only when the material is to be hoisted in large quantities from a great depth, and when the work will extend over a long period of time. This manner of hoisting is more suitable for mining and tunneling, and is very seldom employed in ordinary earthwork excavations, but contractors commonly employ elevators in hoisting materials in the construction of new buildings.

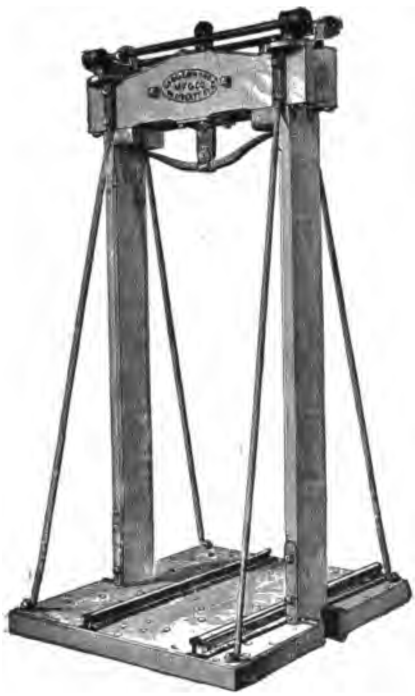


FIG. 90.

Cranes.—The crane is a modern and powerful machine, generally employed for raising or lowering heavy weights or for removing them from one position to another. Cranes are constructed of different shapes, but the most common consists of an upright revolving shaft, with a projecting arm or jib, having a fixed pulley at the upper extremity, over which passes one end of the hoisting-rope or chain, so as to receive the weight, the other end being attached to a cylinder provided with wheel and pinion, by means of which the weight is raised to the required height. By

the revolving motion of the upright portion the load can be deposited on any spot within the sweep of the jib.

Cranes are built of different patterns; some of them have a curved jib, while in others the jib is composed of a straight beam which can be either single or built up of different pieces. In regard to the motive power employed, cranes can be grouped into hand- and steam-cranes; and both of these can be subdivided again into fixed and movable cranes. Fixed cranes operated either by hand or by steam are usually employed on wharfs, factories, storage-houses, etc., while movable steam-cranes only are employed by contractors in the execution of public works. Cranes are very commonly employed in England and Continental Europe, but they do not find great favor among American engineers and contractors. Only two types of cranes will be illustrated here, viz., the crane derrick and the locomotive crane, and their description is given because they are the only ones employed in public works.

Crane Derrick.—The American crane derrick, distinguished from the English steam-crane derrick, which is a true derrick and will be described later on, consists of a vertical mast provided with steel bottom of usual construction, and resting on a wooden block. The mast is kept vertical by means of guys. At a point about two-thirds of the height of the mast is the boom, which is another beam placed nearly horizontally, having an inward inclination so as to facilitate the descending of the weights along the boom toward the mast. On the upper side of the boom there are tracks made of light rails, upon which rolls the trolley that guides the trolley-line. The trolley is moved toward the boom end by the trolley-line running on the engine. Releasing the pull on the trolley-line allows the load to move down the inclination of the boom toward the mast. The engine has complete control of the load, raising it up or down or moving it anywhere the entire length of the boom. The trolley- and hoisting-lines both pass through the casting and pivot at the foot, and thence to a double-drum engine.

The crane derrick illustrated in Fig. 91 is the one built

by the American Hoist and Derrick Company of St. Paul, Minn., and is of 5-ton capacity. The length of the mast varies from 46 to 72 ft., and that of the boom from 35 to 55 ft. The height of the boom from the ground varies from 25 to 39 ft.

The use of the crane derrick is limited to the construction of walls of buildings, setting columns, girders, etc., and since the

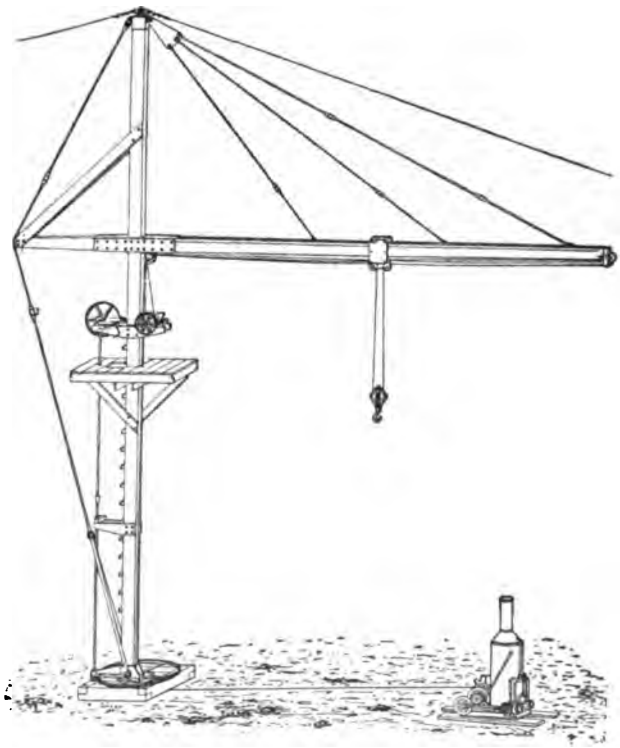


FIG. 91.

boom is generally 30 or 40 ft. from the ground it handles all the work for two stories without moving. By setting up the crane derrick on a trestlework of any convenient height, any building can be entirely completed without removing the derrick. The engine is usually located in the cellar or ground floor, and communication is obtained by means of electric bells.

Locomotive Crane.—The other crane commonly employed in earthworks, especially in Europe, is the locomotive crane illustrated in Fig. 92. This consists of a four-wheeled iron truck running on tracks. On the truck is fixed a large horizontal cog-wheel whose axis is fitted into a socket of an iron frame, with wooden platform upon which are placed the boiler and the engine. In front of the iron frame there is a boom or jib braced by means of iron rods connected to vertical iron stands, and tied to the rear of the

FIG. 92.

iron frame of the truck by diagonal backstay rods provided with turnbuckles. The boom or jib is made in different ways and of different materials, but usually it is made of curved iron except when very long, then it is made of trussed steel. One end of the hoisting-chain is fixed to the upper point of the boom; the chain supports a fall-block, and after passing over a sheave located on top of the boom, is wound around the drum of the reversible engine. In this manner the weight attached to the fall-block can be lifted or lowered at will. The engine is so arranged that by putting into gear another small cog-wheel whose cogs engage those of the large one supporting the platform, the platform and boom and

consequently the attached weight turn a complete circle. This machine is called a locomotive crane on account of being provided with a self-propelling apparatus. All the motions of this crane, viz., the traveling on the rails, the lifting and lowering of the loads, and the turning are actuated by steam generated by the boiler standing on the platform of the truck.

Locomotive cranes are built to run on either standard or broad-gauge track, and their capacity varies from 1 to 35 tons. Fig. 93 illustrates a 5-ton locomotive crane as built by Grafton &

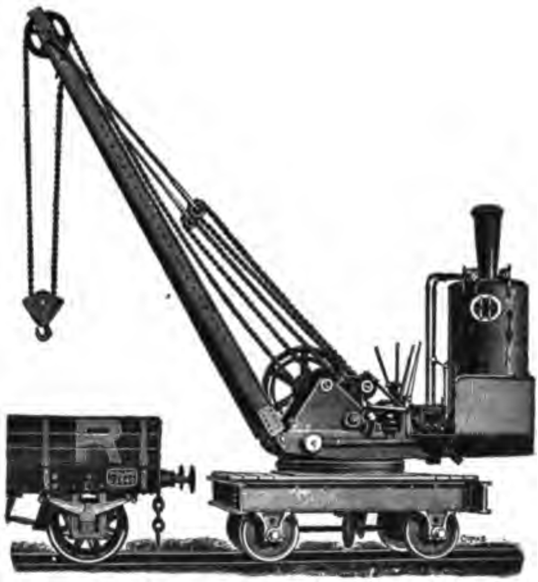


FIG. 93.

Co., Engineers, Vulcan Works, Bedford, England, while Fig. 92 represents a 3-ton locomotive crane built by the American Hoist and Derrick Company. In the locomotive cranes of American build the boom is so arranged that its upper point may be raised or lowered by turning the turnbuckles in the diagonal backstay rods, and this increases the utility of this machine.

The efficiency of the work of these machines varies with their size, and an output of 1000 cu. yds. of earth can be obtained.

Locomotive cranes are very advantageously employed in the excavation of trenches in which the materials are deposited either on one side of the trench or at any point along the line. A 10-ton locomotive crane was successfully employed by Messrs. Farrell & Hooper, the contractors for Sections 7 and 8 of the New York rapid-transit railway, for the removal of the excavated materials from the bottom of the wide trench to the surface of the street. This method of hoisting was employed in that portion of the work extending along Lenox Avenue from 110th to 116th streets, and it was adopted because the crane could be run over the tracks of a disused street-car line running very close and parallel to the edge of the trench.

This locomotive crane, described by the writer in *Engineering* (Jan. 3, 1902), was built at the Industrial Works of Bay City, Mich. The car-body of the crane was made of steel with sills of 15-in. I beams and channels well connected together, and had a decking of steel plates to carry the top. The crane was operated by the engines by means of a train of bevel gearing. To the frame of the crane were secured the boxes of the shaft which worked the mechanism for hoisting the load, slowing the crane, and varying the jib radius. The boiler was 42 ins. in diameter and 9 ft. high, and was surrounded with a jacket of asbestos-wool and planished iron. One side of the boiler carried a coal-bunker with drop-door, while the other had a sheet-steel water-tank. The crane was operated by a double reversible engine with an 8-in.×10.-in. cylinder. Flexible wire rope was used in hoisting. The capacity of the crane varied with the radius of the jib, being 10 tons with a 12-ft. radius, 5 tons with a 25-ft. radius; and if a longer jib was used, 5000 lbs. with a 38-ft. radius. The total weight of the crane itself was 66,000 lbs.

The cost of working with the locomotive crane was found by Messrs. Farrell & Hooper to be less than with any other method of hoisting. This economic advantage was due to the existence of the tracks, along which the crane could easily travel and without interfering in the least with street traffic.

Derrick.—A hoisting-machine very commonly employed by

American engineers and contractors in the execution of public works is the derrick. This can be simply described as composed of a vertical mast resting on a foot-block of special construction, and a long movable jib or boom hinged at the bottom of the mast. The top of the boom is held by a chain or rope which passes over sheaves located both at the top and bottom of the mast, and in such a way that the boom may be raised or lowered at will.

Foot-block.—The foot-block, which really is the foot of the derrick, is made partly of timber and partly of iron. Two square beams 12×12 ins. and 5 or 6 ft. long are placed on the ground, about 1 ft. apart. To these timbers is bolted the base-plate, which is usually made of cast or wrought iron, having on its lower part two vertical plates which support two sheaves called *steps*, because they turn to a right angle the hoisting- and boom-lines of the machine. On the center of the base-plate there is a hollow cylinder of great thickness, from 8 to 10 ins. high, and strengthened by diagonal vertical plates. The cylinder is stepped off about 4 ins. in height in order to receive the hollow part of the mast and boom-bottom, which perfectly fit into it; thus allowing the derrick to revolve on itself, the cylinder acting as a pivot of the system. Fig. 94 represents the iron part of the foot-block as built by the American Hoist and Derrick Company, the timber being omitted to better indicate the plate and sheaves which are placed between the timbers. The mast-bottom, as shown in the figure, is provided with an iron box to receive the lower end of the mast, and it is furnished with projecting iron plates to which are hinged the other plates bolted to the end of the boom.

Mast and Boom.—The mast and boom are usually made of square yellow pine-beams with a cross-section varying from 8×8 to 16×16 ins. The length of both the mast and boom varies greatly. The length depends either on the form of the derrick or upon the work expected from the machine; sometimes the mast is longer than the boom, sometimes instead the boom is twice as long as the mast. Masts and booms made of simple square timbers are employed for lengths not greater than 40 ft. For greater length, to prevent deflection, both the mast and boom

are stiffened with trussed rods passing over a crosstree at the center of the beams, or else they are made of superior material, as steel pipes, or latticed beams made up of different pieces joined together, which are similarly stiffened with trussed rods passing over one or more crosstrees. In this manner derricks have been built with masts 150 ft. and booms 135 ft. long, respectively.

Wire Ropes.—For derrick work, where sheaves, blocks, and drums are necessarily of small diameters, it is necessary to use

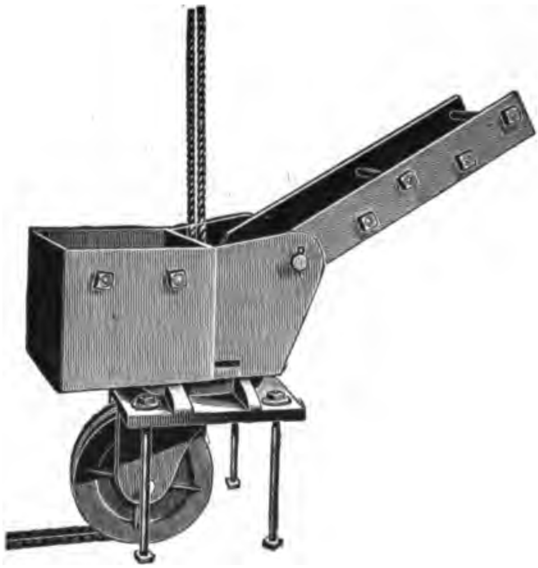


FIG. 94.

wire ropes of great flexibility, thus avoiding fracture of the wires from short bends. They are usually made of six strands, nineteen wires per strand, with hemp center, the wires being of crucible or plow steel, the latter being the stronger and also the more expensive. The safe working load of the wire ropes is usually taken as one-fifth or one-seventh of the breaking load. In the table on p. 259 are given the diameter, weight, and breaking and working loads of the standard steel hoisting-ropes most commonly employed.

A derrick is able to make three different movements which

are regulated by different ropes: viz., the hoisting-, the boom-, and the slewing-rope. The hoisting-rope has one end fixed to the top of the mast, and the other end to one of the drums of the engine. From the drum it goes around one of the sheaves of the foot-block, and turning over another sheave located near the foot of the mast goes to the top of the boom, where it passes over another sheave, goes to support the fall-block, and its end is fixed to the top of the boom. By revolving the hoisting-drum of the engine, the fall-block, together with the attached weight, may be raised or lowered at will.

The second movement of the derrick is to raise or lower the boom, and consequently to get it closer or farther from the mast. This is obtained by means of a second rope called the boom-line, which is wound around another drum of the engine, and passes around the other sheave of the foot-block; thence to the top of the mast, where it turns again by passing over a sheave, and thence to and through a block attached to the upper extreme of the boom; and thence again to the top of the mast. By revolving the second drum of the engine commanding the boom-line, the upper end of the boom may be drawn either near to or far from the mast.

The third movement of the derrick, which is to slew the mast around on its axis, and consequently also the boom with the attached weight, is usually made by hand. For this purpose another rope, ordinarily of manila, is tied to the upper end of the boom, and a workman pulls the boom to the required place. Such hand movement, however, is too slow and expensive, especially when a weight of 2 tons or more is attached to the fall-block, since then two or even three workmen are required to slew the boom. For the sake of economy this third movement is also made by machine, and then the foot of the mast is provided with what is called a bull-wheel. This consists of a large horizontal wooden wheel furnished with a grooved rim to prevent the slewing-line from working off. The wheel is strongly braced to the bottom of the mast, and, as indicated in Fig. 95, also to the boom to relieve the hinges of the boom from side twists. Two guiding-sheaves

are placed horizontally on the foot-block to direct the two lines to the slewing-drum of the engine. The engine in such a case is provided with three drums—one for the hoisting-, a second for the boom-, and the third for the slewing-ropes. By this simple arrangement one man at the engine can lift the load and slew it to the desired place in the same length of time that it takes to do only the lifting in derricks not furnished with bull-wheels. This slewing device was at first introduced in the most powerful derricks, as those employed in the excavation of the Chicago Drainage Canal, but it is now found in nearly every work of importance. When special three-drum engines are not at hand, the lines of the bull-wheel for slewing the boom are commanded by the winch-heads of the two drums, and in such a case the slewing of the boom is made after the hoisting has been completed, instead of the two movements being simultaneous, as with the three-drum engine.

An enormous variety of derricks is found on the market. Nearly every manufacturer has his own particular way of arranging the sheaves, the top of the boom and mast, the foot-block, etc., giving rise to the claims of several patents, every one, as usual, being considered a great improvement. Really all derricks are similarly constructed, and differ only in small details. For the sake of facilitating the description of these hoisting-machines, they will be divided into three groups: viz., stiff-leg derrick, guy derrick, and traveling derricks.

Stiff-leg Derrick.—This derrick, like any other, consists of a vertical mast, and a boom hinged to the foot of the mast. It rests on a foot-block which differs somewhat from the one already described, because instead of the two short timbers placed parallel one to another, the timbers in the stiff-leg derrick meet at right angles and are very long; they are called sills. The mast is kept vertical by means of two backstays abutting, with one end near the extremities of the sills, while at the other end are bolted iron plates furnished with a pinhole. At the top of the mast there is a steel pin projecting not less than 6 ins. in length. The pinhole of the backstays clasps the pin and keeps the mast vertical, and

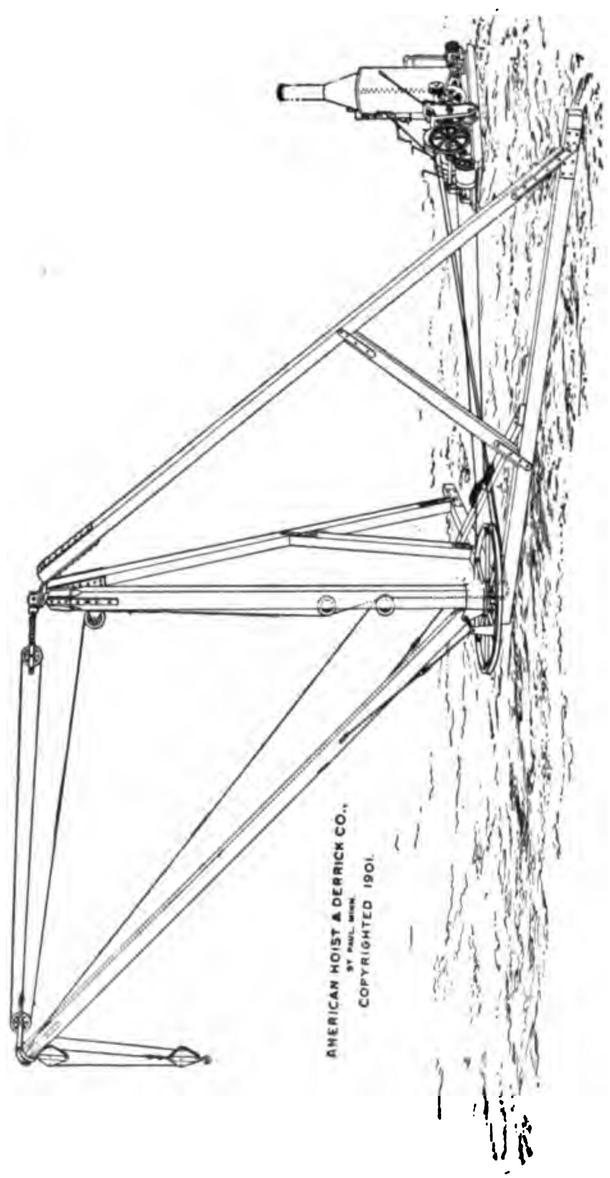


FIG. 95.

yet allows it to turn around on its axis. The sills and consequently the backstays being at right angles, the boom can be slewed three-quarters of a circle.

Stiff-leg derricks are built of any form, dimension, and capacity. Those most commonly employed in public works have a boom 25 ft. long, with a capacity varying from 2 to 3 tons. In this kind of derrick the boom is usually longer than the mast, and it is made of timber, iron, or steel, and sometimes is reinforced by truss-rods passing over a crosstree at the center of the beam.

Fig. 95 illustrates a stiff-leg derrick of ordinary construction, provided with a bull-wheel for slewing the boom, as built by the American Hoist and Derrick Company.

Guy Derrick.—The mast of the guy derrick rests on a foot-block of a similar construction to the one described and illustrated by Fig. 94, and the top is provided with a steel gudgeon-pin. The mast is kept vertical by means of wire ropes or guys spreading radially from the top. In order to keep the mast perfectly vertical, it is necessary that the ropes be very tight. The ropes are made fast to the top of the mast by means of a guy-cap or gudgeon-plate, as it is more commonly called. This consists of a wrought-iron circular plate provided with a circular hole at the center to receive the gudgeon-pin of the mast, and six or eight small holes around the edge and of such dimensions as to allow the passage of the guys. To prevent the breaking-off of the wires of the rope either from short bends or rubbing against the sharp edges of the iron guy-cap, the holes are molded into a thimble shape, as indicated in Fig. 96. The other ends of the

FIG. 96

guys are tied to surrounding trees, or else to a short but very strong beam, placed horizontally on the ground, called the dead

man, and kept in place by a big pile of stones. With more powerful derricks the guys are made light by means of turnbuckles attached to them.

In the guy derricks the boom is usually shorter than the mast, and when the guys are very long or when they are tied to elevated points, the boom can be slewed through a full circle. Both boom and mast can be made of square timbers, or built up of iron beams or steel pipes; and when of great length they are reinforced with truss-rods and crosstrees.

Guy derricks are made of any dimension and capacity. There are derricks with 150-ft. mast and 135-ft. boom, having a capacity of 10 tons, while there are others of much smaller dimensions but of 50-ton capacity. Since the mast should be perfectly vertical it is more difficult to set up a guy than a stiff-leg derrick. The verticality is obtained by pulling the various guys to the required point. It takes time and patience to set up guy derricks. In regard to the cost of the machine this varies with the size and capacity. As a rule it can be assumed that derricks of ordinary dimensions will not cost more than $200 each. It takes nearly six days' work to set up a guy derrick, while only one-half or even one-third of this time is required in setting up a stiff-leg derrick.

Fig. 97 shows a hand-power guy derrick of ordinary construction.

Traveling Derrick.—The other kind of derrick which will be here illustrated is the traveling derrick, represented in Fig. 98. This consists of a platform car mounted on a four-wheeled truck running on tracks. At the front edges of the car there are two vertical posts with a crosspiece on top, and this frame is made stiff by means of the backstays provided with iron plates bolted at the top of the vertical posts, and at the rear end of the car. At the center of the crosspiece of the frame there is an iron plate cored in the middle so as to receive the gudgeon-pin of the mast, which stands on another iron plate inserted in the platform of the car and provided with a hollow cylinder into which fits the bottom of the mast. This is made of iron with the flanges supporting the axle of a sheave and the hinges of the bottom of

the boom. Underneath the platform of the car there is another sheave. Boiler and engine are located in the rear of the car, thus

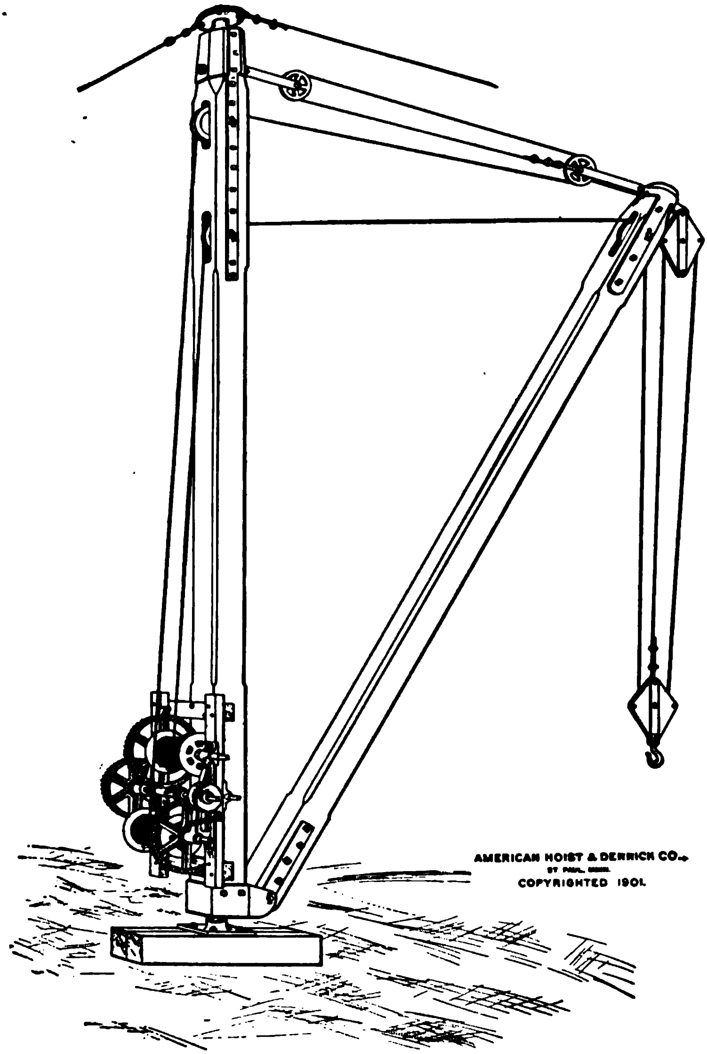


FIG. 97.

preventing the tipping of the derrick by counteracting the weight attached to the boom. When excessive weights are raised or

lowered, it is necessary to insure the stability of the apparatus by adding ballast on the car.

The traveling derrick as well as other derricks is capable of three movements which, as has been already seen, are made by the hoisting-, the boom-, and the slewing-lines. The arrangement of the hoisting-line is similar to that of the stiff-leg or guy derricks,

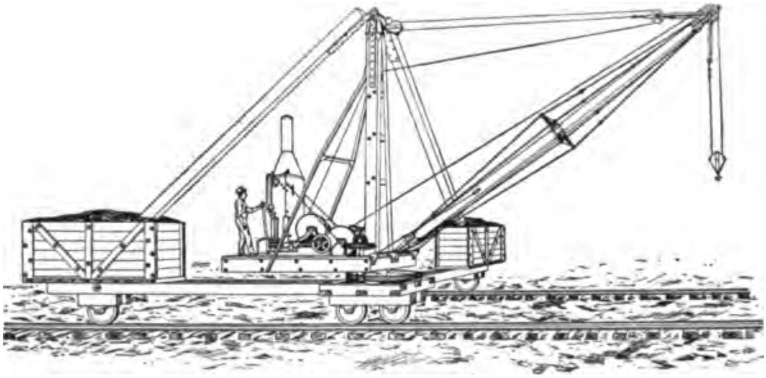


FIG. 98.

while the arrangement of the boom-line is a little different. This is attached to a pulley fixed at the top of the boom, and turning around another pulley attached to the top of the mast, passes over the first to the top of the boom. It returns again to the mast, passing over a sheave placed at its top, and then assumes a vertical direction, turns on another sheave inserted above the crosspiece of the frame, and goes to one of the drums of the engine. When the slewing is done by hand, a third line is inserted at the top of the boom; but if it is done by machine the bottom of the mast is provided with a bull-wheel.

The traveling derrick, as its name clearly indicates, is self-propelling. This is accomplished by using a double cylinder and double-drum reversible engine provided with locomotive attachment for the car-wheels, which is more economical than to have a special engine for the propelling movement of the car.

In the traveling derrick the boom is always longer than the mast, and in order to avoid the tipping of the car or the employ-

ment of excessive ballast, it is a good practice to use booms not longer than three times the gauge of the track. The gauge of the track varies from the standard distance of 4 ft. 8½ ins. up to 20 ft., depending upon special conditions of the locality.

The traveling derrick is found particularly useful in the construction of retaining-walls, in laying the foundations of important buildings, in erecting structural ironworks, etc., and in many cases it may be made to take the place of several stationary derricks. It is found very convenient in trench-works, as, for instance, in building sewers, laying water-pipes and gas-mains, etc. In these cases a track is laid on each side of the trench and the car straddles the ditch.

CHAPTER XV.

TRANSPORTING EXCAVATED MATERIALS BY AERIALWAYS.

In working through rough and broken country intersected by ravines or streams, or through city streets where roads are too expensive to construct or are undesirable for other reasons, the transportation of excavated materials may be very conveniently accomplished by means of aerialways. From time immemorial aerialways in primitive forms have been used for conveying different materials from one point to another by means of a rope stretched between two points. The writer, however, was surprised to see in a book written by Dr. Hook, and published in London in the year 1692, a contrivance described and illustrated which Sir Robert Southwell saw used at Brandenburg for the speedy conveyance of earth to fill up or raise ground, etc. It was really a perfect aerialway, and even more complicated than many of the contrivances recently patented. It is only in the last few years, however, that aerialways have found extensive employment in the transportation of materials for mining, industrial, and public works.

For the sake of convenience, under the general name of aerialways there are included here all the methods of conveying excavated materials in such a manner that the cars, skips, buckets, scales, etc., instead of running on tracks laid on the ground, are by some means suspended and moved on beams or ropes suspended in the air. According to this definition and in order to review in order the various means of conveyance, these aerialways are divided into true aerialways and telphers. In the first group are included all aerialways in which the cars or skips containing the material are moved by means of ropes commanded by engines; telphers

are aerialways in which the cars are self-moving on the suspended track, being provided with electric motors. In regard to the nature of the trackway true aerialways can be divided into two groups: viz., transporters and cableways. They are called transporters when the trackway is formed by rigid beams, and cableways when it is made of rope. Again, both transporters and cableways can be subdivided, according to the manner of working, into simple transportation-lines, when several cars or skips run at the same time on the trackway, and all remain at the same fixed distance from the track; and into hoisting- and conveying-machines when only one car or skip of large capacity runs on the trackway, thus acting as a means of conveyance, and is by some device raised or lowered so as to act also as a hoisting-machine.

Aerialways.	Cars moved by ropes commanded by engines.	Trackway made up of rigid beams.	Transporters.
		Trackway made up of wire ropes.	Cableways.
	Cars provided with electric motors and self-propelling.		Telpherage.

TRANSPORTERS.

According to the definition given above, aerialways in which the track is composed of rigid beams are called transporters. They can be used either as a simple means of transportation or as hoisting- and conveying-machines.

The writer does not know of any transporter used exclusively as a means of transferring materials from one point to another, with the exception of the coal-handling devices, which, up to a certain limit, can be considered as true aerialways. In fact, they consist as a rule of a double endless chain, to which the buckets are attached and guided on tracks made up of rigid beams. These transporters, although convenient for factories or piers, have, to the knowledge of the writer, never been employed in public works or in mining. The reason they are not used is on account of being far more expensive than cableways of the same capacity, because the trackway, being composed of rigid beams, has to be supported

every few feet, while cableways can be constructed with spans running up to thousands of feet.

It is a very easy matter, however, to imagine how a transporter used exclusively for transferring materials from one point to another should be arranged. The trackway could be made up of two parallel lines, one for the cars loaded with material, and the second for the empty cars traveling in an opposite direction. A loop at each end of the tracks will join them and make them continuous. The tracks should be suspended in some way, either to the roof of the factory, shed, or pier; or else held up above the ground-surface by means of trestle-bents. On the tracks may travel the buckets carrying the materials, and they can be in such numbers as to be only a small distance apart. The movement of the buckets may be effected by means of an endless hauling-rope turning around two grooved horizontal sheaves of great diameter located just below the loops at the ends of the tracks. The movement of the hauling-rope is caused by revolving one of the sheaves, and can be regulated by the rapidity of revolution of the shaft. The buckets could be of the same shape and design as those used with the Otto, Bleickert, and similar cableways, provided with a small truck for running on the tracks and a grip for connection to the hauling-rope. If the line were provided with an automatic loading device and an arrangement for dumping the buckets, the transporter thus constructed would certainly give perfect satisfaction in regard to operation, but not, perhaps, in cost, which would be higher than for a cableway.

Transporters, however, are used as hoisting- and conveying-machines, and they not only transfer the materials from one point to another, but they lower and raise the bucket or weight between the tracks and the floor. These kinds of transportaters are provided with only one track, upon which the single bucket travels back and forth by means of an endless rope, and is raised or lowered by means of a second rope. Both ropes are commanded by a drum on a double-drum reversible engine.

Lidgerwood Transfer.—Of the hoisting and conveying transporters, the simplest one is the Lidgerwood transfer. This is

provided with a double-track line for the four-wheeled truck, to which is suspended the bucket containing the material to be transported.

The trackway is composed of two rails which can be built in different manners; they can be made of two wooden beams provided with angle-iron at the edges, as at *A*, Fig. 99; or of two small,

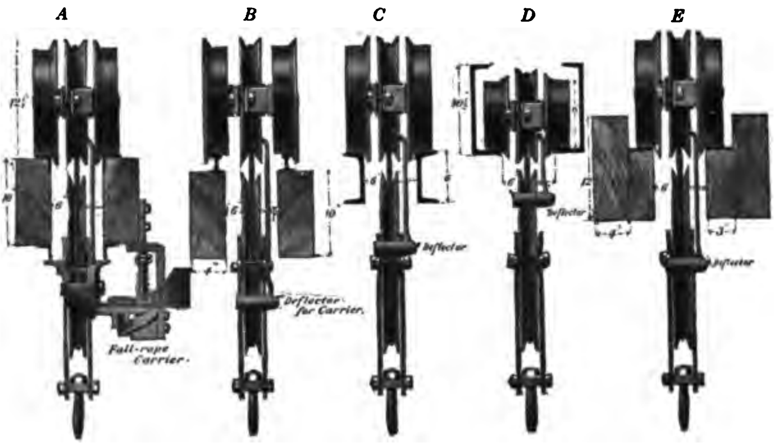


FIG. 99.

very light rails placed upon longitudinal wooden beams, as at *B*; or they can be made of two channel-irons upon which the wheels of the truck may run either above the upper flange, as at *C*, or on the lower flanges and within the channels, as at *D*. In any case the trackway is suspended from the ceiling or roof by means of hangers, but it could also be easily supported by iron or wooden bents.

The carriage of the Lidgerwood transfer consists of a truck resting on four small flanged wheels. The truck supports two sheaves around which the fall-block rope carrying the suspended load is wound. The body of the carriage varies in form, according to the material to be carried. The carriage is moved along the trackway by means of an endless carrying-rope, whose return is supported by sheaves placed between the hangers of the trackway. The hoisting-rope is supported by special carriers placed

below the tracks. These carriers are composed of two distinct parts held close together by means of springs; one of these parts is provided with a sheave. The carriage is furnished with a deflector which pulls apart the carrier, and when the carriage is well past, the carrier will resume its former position and the hoisting-rope will then be supported again by the carrier. The hoisting-rope carriers are placed at a distance of about 50 ft. apart.

The Lidgerwood transfer (Fig. 100) is operated by a double-

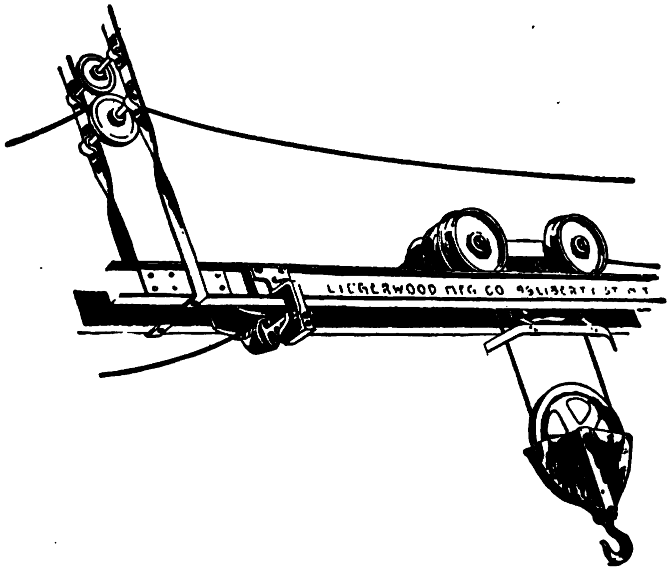


FIG. 100.

drum reversible engine, one of the drums commanding the carrying-rope, while the other drum regulates the hoisting-rope.

Loads of more than two tons can be easily handled by this transporter, which is found very convenient for conveying materials in warehouses, coal-sheds, and coal-houses, but not in public works. It has been described on account of its simplicity, and because many machines usually employed in the excavation of trenches for sewers, water-works, and other purposes are built on the same principle.

Moore Trenching-machine. — The trenching-machines, which are now so commonly employed by contractors in public works, are simply hoisting and conveying devices running upon rigid trackways. Fig. 101 illustrates the Moore trenching-machine built by the Moore Manufacturing Company of Syracuse, N. Y. This consists of a trackway composed of two light steel rails, elevated

FIG. 101.

not less than 10 ft. above the ground, and supported by a series of steel or iron bents braced together so as to form a solid structure. The feet of the bents are provided with small flanged wheels, in order that they may be easily moved along other tracks laid on the ground, and on both edges of the excavated trench.

On the upper track moves the conveying-car, made up of a

four-wheeled truck provided with a platform having an open space in the center; on this platform stands the operator. The front and back of the truck is connected with an endless rope wound around the drum of a reversible engine, thus allowing the truck to go back and forth along the upper tracks. The return of the endless carrying-rope is provided for by means of sheaves located at the head- and tail-tower of the system, and supported also by sheaves mounted high on the conveying-car. Either higher or lower than the sheaves supporting the returning carrying-rope, there are two more sheaves for the support and direction of the hoisting-rope, which, through the opening in the center of the platform, may reach the bottom of the trench.

The machine is operated by a double-drum reversible hoisting-engine, one drum commanding the endless carrying-rope, and consequently the movement of the conveying-car along the trackway; the other drum regulating the hoisting-rope. The fall-block suspended to the hoisting-rope carries the bucket, which may descend to the bottom of the trench or be raised to a height just below the trackway of the conveying-car. When the bucket is in this position, the drum of the carrying-rope is put into gear and the bucket moved along the trackway or stopped at any desired point, where the bucket discharges its contents either into a car so as to be hauled away, or into the rear portion of the trench, where the required work has already been completed.

At the front end of the apparatus there is a platform car upon which are mounted the engine and boiler as well as the head-tower, the tail-tower being similarly mounted on another platform car at the rear end of the machine. Both the towers and the bents being mounted on wheels, the machine may be easily advanced, thus following the progress of the work. The time required for advancing the machine can be assumed at 60 ft. in five minutes.

The theoretical capacity of the machine is one bucket a minute; the capacity of the bucket being a cubic yard, the work of the machine will be 60 cu. yds. per hour. In practical works, however, such a result is never obtained, because the work inside

the trenches proceeds very slowly on account of the narrow space in which the men work, and also on account of the strutting and the construction of the work, for which purpose the trench was opened.

The Moore, as well as other similar machines found on the market, are extensively employed to-day on public works, because they greatly reduce the expense of construction. One of the great advantages is that they remove the necessity of piling

FIG. 102.

dirt in the public streets and blockading the traffic, especially in narrow streets. With these machines the earth excavated at the head of the line is conveyed toward the rear and employed in backfilling the trench after the construction is cômpleted. The surplus of excavated materials is directly loaded from the buckets into wagons, which may go under the trackway, as indicated in Fig. 102. With these machines the work proceeds with the greatest regularity, efficiency, and economy.

The Brown Hoisting- and Conveying-machines. — Another transporter which gave magnificent results in the excavation of the Chicago Drainage Canal is the Brown hoisting- and conveying-machine, built by the Brown Hoisting and Conveying Machine Company of Cleveland, Ohio. The machine, illustrated in Fig. 103, was built to answer all the requirements of the work, which were to have a traveling conveyor arranged in such a way that the material excavated from the bottom of the proposed canal could be raised and deposited to a much higher point on the spoil-banks located alongside and at some distance from the shore. The trackway was made of an inclined cantilever supported by a central tower. The following description of the machine is taken from *Engineering* of London.

The Brown hoisting- and conveying-machine is carried on four tracks of standard gauge by four trucks of four wheels; the distance apart of the tracks between centers is 37 ft. The tower, which is mounted on a platform carried by the trucks, is a strongly framed structure. It consists of two pairs of columns braced together; the front pair of columns is 53 ft. in height and the back pair 60 ft. 8 in. This difference in height corresponds to the necessary inclination of the cantilever, which is set at an angle of 12° 50′. Upon the platform, between the columns, is placed the power station, from which all the required manœuvres of the cables, etc., are operated and the power required for propelling the derrick derived. The total length of the cantilever is 355 ft., which allows an overhang of about 150 ft. into the canal-bed, while the farthest point for dumping is nearly 200 ft. from the edge of the canal. The length of travel of the buckets is, however, only 353 ft. The height of the lower end of the cantilever above the bed of the canal is 53 ft., and that of the upper end is 93 ft. above the natural surface. The buckets, holding about 1½ yds., are attached to the end of the hoisting-cable and raised to the under side of the cantilever, when a second and hauling-cable transfers them for the whole length of the cantilever or to such a point as may be desired for dumping. This work is performed in the engine-house on the tower, where three different

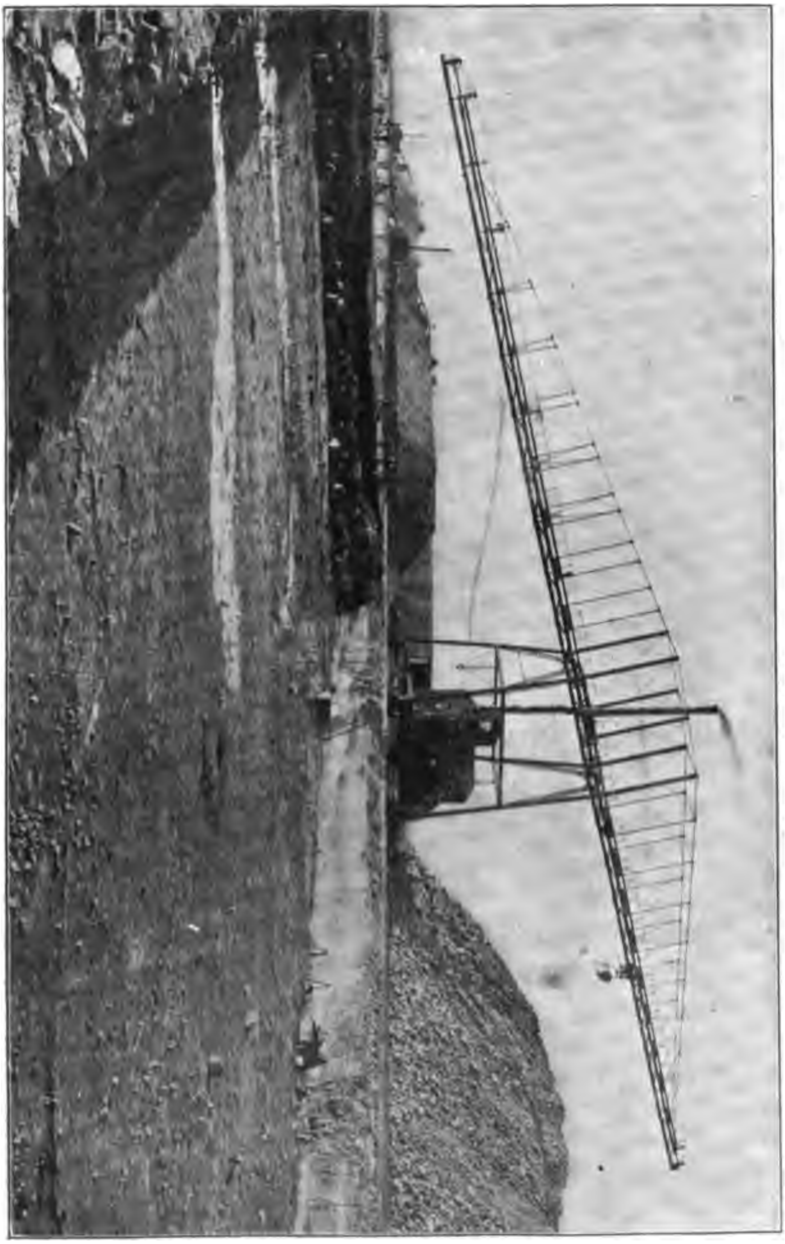


Fig. 103.

motions are used and controlled by three levers. One lever hoists the bucket from pit to truss, another transfers it to the other cable and raises it along the truss till, striking the trip, it automatically dumps and then returns to the pit, and a third lever moves the whole derrick along the track.

The average speed of the cantilever along the track is about 150 ft. per minute, but as much as 400 ft. per minute has been made. The total weight of truss, tower, and 120-H.P. $10\frac{1}{2}$-in. $\times$ 12-in. engine is about 150 tons. The buckets used are of iron and steel and contain 75 cu. ft. water measure. The records of different cantilevers for long periods of time show the actual working load to be from 1.5 to 1.7 cu. yds. in place measurement. The greatest practical work of this machine was obtained by two of these cantilevers working in Section 11, which carried 627 cu. yds. per day in a total of forty-nine days worked. Nine buckets are usually required for the regular service of these cantilevers and a gang of five men was employed for each bucket in the canal-bottom. The cost of working the Brown conveyor is given as 3.58 cents per cu. yd., including all the wages, coal, stores, and repairs connected with the running and maintenance of the machine.

Temperly Transporter.—Before closing this review of aerialways running upon rigid tracks it is necessary to mention the Temperly transporter, which is one of the simplest and which is extensively employed for different purposes. The Temperly transporter is a hoisting- and conveying-machine employing a suspended beam as a trackway. The special feature of this transporter is the automatic carriage of novel design provided with a simple automatic device by which the carriage can be held stationary at various points along its track while the load is being lifted or lowered, and which sustains the load while the carriage is moving. The various movements of the carriage mechanism are interlocking. For example, the carriage is not released from holding to the beam until the load is released from the carriage, and, vice versa, the load is not released from the carriage until the carriage is firmly locked to the beam. Fig. 104 shows the interlocking mechanism.

The trackway is generally made of a single iron I beam, and the carriage travels upon the lower flange with two wheels, one on each side of the web. The beam is generally suspended by means of guys and can be entirely suspended, or one end may abut against a mast or some other firm support. It may work at any

FIG. 104a.

angle and the higher end may be either inward or outward. When the beam is fixed as in factories, warehouses, etc., it can be made of any length, but the portable beam is generally from 30 to 60 ft. long. To reach out long distances a tubular boom is preferable to the I beam, and in such a case the carriage travels on a track suspended on the lower side of the boom. In order to stop the

carriage at different points the bottom of the lower flange of the I beam is provided with stops at intervals, in accordance with the requirements of the case, usually 5 ft. apart. At any of these points the carriage can be arrested at the will of the operator and the load lowered or hoisted. The stops on the beam and

FIG. 104*b*.

the manner in which the carriage is stopped are clearly indicated in Figs. 104*a* and 104*b*.

The operations of lifting, transporting, and lowering the load are effected by the simple action of hauling in and paying out a single rope, and any form of a single-drum hoisting-engine may be used for working the transporter.

The great success achieved by the Temperly transporter, which in the last few years has been adopted by all the maritime powers of the world for coaling vessels, should attract the attention of engineers and contractors to the fact that it affords one of the simplest and most economical means of hoisting and conveying. The Temperly transporter is built to carry loads from 1000 to 3000 lbs., it is easily set up and removed, since its weight, the carriage being included, does not exceed 1 ton. It is handled by one man at the engine, and the work of the machine is from 40 to 60 tons per hour.

CHAPTER XVI.

TRANSPORTING EXCAVATED MATERIALS BY CABLEWAYS.

CABLEWAYS are aerialways in which the carrier is suspended to a rope either traveling with it or simply moving along it. Within the last thirty years this simple and economical means of transportation has found numerous applications, and it is now extensively used in mining as well as in public works. A large variety of cableways is found on the market, and since the manufacturers insist on introducing them under the name of the various inventors there is great confusion.

According to Mr. J. Pearce Roce, cableways can be broadly divided into two types. First, that in which a plain endless rope both suspends the loads and moves them, and second, that in which the loads are suspended from runners drawn along fixed cables by means of a separate traction rope. Cableways of the first type can be divided again into two groups: one in which the carriers hang from the rope and move with it through frictional contact, and another in which the carriers hang from the rope and move with it, being rigidly fixed in position on the rope. This is the principle of the Hodgson and Hallidie systems. The cableways of the second type, in which the carriers are suspended to a fixed rope and are hauled by a traction rope, can be divided also into two other groups, as, for instance, into cableways in which there is only one rope used as trackway, or into cableways in which the trackway is formed by two parallel ropes. When there is only one rope, there is also only one carrier, which is drawn to and fro by means of an endless hauling-rope. All the numerous hoisting- and conveying-machines which in the last few years have been extensively used in public works, as, for instance, the Carson trenching-machine, the Locke & Miller, the

Flory, and other cableways, belong to this group. Cableways may be also made up of two fixed parallel ropes with an endless hauling-rope, so that the carriers travel in one direction and return in the other. The Otto, Bleickert, Leschen, and similar aerialways are constructed on this principle.

All the methods of transportation indicated above are used for hauling materials on horizontal or nearly horizontal trackways, but in many cases the difference of level between the extreme stations of the cableways is great, and then the cableways used are known as inclined cableways. These, however, can be made of one fixed rope on which the carriers uncontrolled by hauling-ropes are allowed to run down at a high speed, or else only one carrier is used, and this is controlled by the hauling-rope. To the former class belong the apparatus called "shoots," and to the last inclined cableways proper.

For sake of simplicity cableways will be reviewed here grouped in the manner indicated in the following table. The limits of this book do not allow a long discussion of this subject, but further information can be obtained from the catalogues of the several manufacturers, especially that of Bullivant & Co., Ltd., of London, who employ and manufacture the various ropeways designed by Mr. W. Carrington, M.Inst.C.E., one of the pioneers and perhaps the most competent engineer in this line of work in the world.

Cableways: Carriers moved by ropes.	On horizontal or near horizontal trackways.	Carriers hanging to an endless running-rope.	Carriers hanging from a rope moving through frictional contact.	Carrington's system.
			Carriers hanging from a rope and moving with it, being rigidly fixed in position on the rope.	Hallidie's and Hodgson's systems.
		Carriers moving along fixed ropes.	Only one carrier hanging from a fixed rope and moved by a hauling-rope.	Carson trenching-machine, Locke & Miller, Flory's, Roebling's, etc.
			Carriers running on two parallel ropes and moved along by means of an endless hauling-rope.	Otto's, Bleickert's, Lescher's.
	On inclined trackways.	One fixed rope.	Many carriers uncontrolled by rope, descending by means of gravity.	"Shoots."
		....	One carrier controlled by a hauling-rope.	Inclined cableway.

Carrington System.—This system in which the endless running-rope has carriers hanging therefrom and moving with it through frictional contact is described by the inventor, Mr. W. Carrington, in the following way:

"This system is provided with a driving-gear at one end fitted with a driving-drum, varying from 5 to 10 ft. in diameter and arranged with suitable gearing for receiving the power-steam, water, or even horse-power in the case of smaller lines. At the opposite terminal a similar wheel is placed and provided with tightening-gear. Round these two wheels an endless band of wire rope is placed. Intermediately between them the wire rope is carried on suitable pulleys of diameter, varying according to the size of the rope, the former being carried on posts of iron or timber, spaced about 200 ft. apart, and of suitable height to enable the carriers to clear intervening obstacles, and also to regulate, to a certain extent, the general level of the line. The carriers hang from the rope and are enabled to pass the supporting pulleys by means of a curved hanger, which, pivoting in the V-shaped saddle which rests on the rope, attaches at the lower end to the receptacle by means of a hook. The saddle, in an iron frame, is fitted with wood or rubber, or composition friction blocks, by means of which the necessary friction on the rope is obtained, which enables the carrier to pass with the rope up steep inclines and over pulleys."

The frame which carries these friction pieces is fitted with two small wheels carried on pins attached to it, which are called shunt wheels, and are employed for removing the carrier from the rope at the terminals and at curves where shunt-rails are placed. These rails are held in such a position that when the carrier approaches the terminal, the small wheels engage on it, and running up a slight incline, lift the friction or clip-saddle from the rope and enable it to pass to where the loading and unloading is required to be done, or round the curve wheels. The impetus derived from the speed of the rope (about four miles per hour) is sufficient to enable the carrier to clear itself automatically from the rope without difficulty.

This method of cableways is used for industrial purposes, but

not in ordinary excavation works; it is advantageously employed where the quantity to be carried does not exceed 1 in 3; where the individual loads do not exceed 6 cwt.; and also where the section of the ground does not necessitate spans of greater length than 600 ft. Longer spans, steeper inclines, greater quantities, and heavier loads can be carried by this system, but not so advantageously as by another system referred to hereafter.

Hodgson and Hallidie System.—The Hodgson's system takes the name from its inventor, Mr. Charles Hodgson, who in the year 1868 secured a patent for this means of transportation. This has the driving-gear, the tightening-gear, the endless rope, and the pulleys, as in the method described above; the only difference being that the carriers are rigidly fixed in position on the endless running-rope, and consequently they must go where the rope goes. Such an arrangement allows steep inclines to be surmounted, and a great advantage is that the carriers can go around both the driving- and tightening-gear without the necessity of

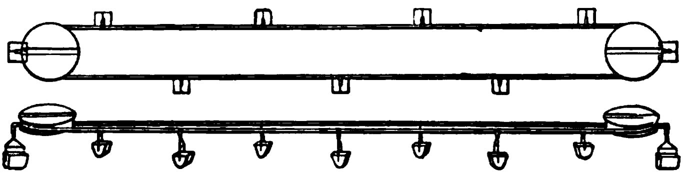


FIG. 105.

having terminal stations, as in the former case. The driving wheel is generally in the form of a special clip-drum, and the terminal wheel, where the tightening takes place, is arranged so that the passing round of the carriers is easily effected.

The unloading of the material is easily done by allowing the carrier to strike a catch, causing the bucket to capsize or open at the bottom. The loading, however, is more complicated, and many devices have been devised for this purpose which chiefly consist in hoppers located near the terminal station discharging into the carriers and moving with them and returning immediately to their former position so as to be ready for a new carrier.

The Hodgson and Hallidie system is very convenient for

carrying continuously materials over ridges of great elevation, and where sudden and frequent changes of level have to be operated over. The Bullivant Company, Ltd., after designs of Mr. Carrington, who was an associate of Mr. Hodgson, and from whom we have obtained the present description and information, has built a ropeway of the Hodgson system in Japan, carrying materials up a mountainside which has an incline of 1 in $1\frac{1}{2}$, the length of the road being nearly one mile. The diagram given in Fig. 105 indicates both in front view and plan the manner of working of the Hallidie and Hodgson systems of ropeway. Fig. 106 shows a carrier for use with this kind of ropeway suitable for carrying earth, sand, crushed stone, and in general any rock material.

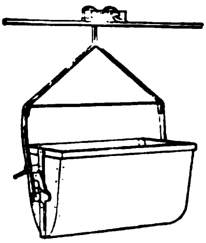


FIG. 106.

One of the most efficient grips for connecting the bucket to the traveling rope is the Brown Aerial Tramway Clip, controlled by Broderick & Bascom of St. Louis, indicated in Fig. 107. The grip consists of three forged strap-bands encircling the rope, and the bucket is suspended to a yoke hinged to the strap-bands.

FIG. 107.

The Otto, Bleickert, Broderick, and Similar Cableways.—These are all constructed on the principle in which several carriers run at the same time on an endless fixed rope used as a trackway, while they are moved along by means of an endless hauling-rope.

The cable-track is supported at different points, and the entire line is thus divided into various spans. In these systems of aerialways the cables are very tightly stretched, thus securing to the loads a comparatively direct path, which means that they are not subjected to great fluctuations of rise and fall or wave motion. On each line there are two track-cables, one for the loaded skips and the other for the return of the empty ones. The lines are parallel and placed at such a distance as to prevent the carriers loaded with materials and running in one direction from inter-

fering with the empty ones running in the opposite direction. As a rule the ropes are placed 7 ft. apart.

The track-cable is made stationary by means of intermediate supports placed at distances varying from 150 to 200 ft. apart. These consist of high posts having a crosspiece on top for the support of the track-cables. The crosspiece is made stiff by two struts abutting against the post, and to increase the stability of the post two wooden stays are placed so as to enlarge its base. With greater spans the supports are on especially constructed towers. Since the cables are supported continuously along the line, these cableways can be made of any length. Thus, for instance, there is a cableway of the Bleickert system in Syracuse, N. Y., which is 16,500 ft. long, and the one built across and over the famous Chilcott Pass in Alaska is 9 miles long. Lately Leschen of St. Louis built a cableway over 16 miles long for the transportation of the minerals of the North American Copper Co. at Encampment, Wyo. Another long cableway founded on this principle was built by the Otto Company in the year 1888 in Spain, over a country impassable to any other means of transportation. It was constructed to convey the ore from the Serena de Bedar to the seacoast of Garruche. On this line there are gradients of 1 to 3, and spans of nearly 1000 ft.

The end-stations (Fig. 108) are provided with horizontal

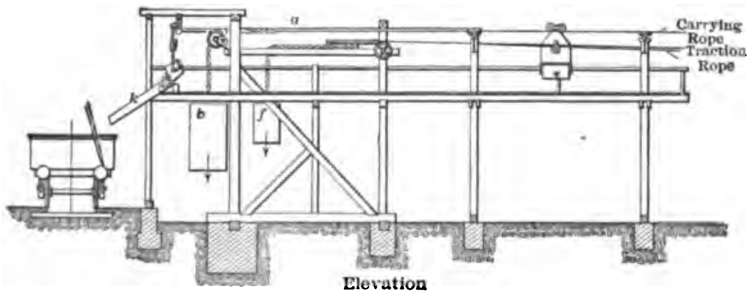


FIG. 108.

sheaves for the continuous revolving of the endless traction-rope, which is obtained by connecting the shaft of one of the sheaves with a driving-engine located near by. The carrying rope is con-

nected with an iron loop upon which the cars are run after having been automatically detached from the traction-rope. The cars are automatically loaded and unloaded, and brought back to be attached again to the traction-rope.

The complete carrier used with this system consists of a carriage (Fig. 109) which is made up of two grooved wheels having in their middle a pivoted hanger which supports the bucket. The hanger is constructed in such a way as to allow the passage of the carriage over the supports without interfering with them. The carrier is attached to the traction rope by means of a grip. When the cars arrive at either terminal, or other station, the grips detach automatically, and the carriages are switched off onto the shunt-rails, supported by the structure of the station. It is generally during the running of the cars onto these shunt-rails that they are automatically loaded or discharged as the case may be.

FIG. 109.

The differences between the Otto, Bleickert, Leschen, and other similar systems, although magnified and highly praised by the various manufacturers, are not important for those who consider the cableways from a general point of view of hauling apparatus. The differences chiefly consist in the form of carriages and hangers, in the grips of the hauling-rope, in the saddles supporting the cable-tracks, in the manner of shifting the carriers from the rope-way to the shunt-rails, in the manner of loading and unloading the cars, etc. All these details must be examined with great care by the engineers and contractors before deciding which machine to buy, and which would be the most appropriate one in the particular case that he has to deal with.

This system of cableway, in which the carriers run on an endless fixed rope and are moved along by means of a hauling-rope, is convenient for the transportation of not less than 400 tons of

materials per day, and over rough country where the inclines exceed 1 in 3 and the spans exceed 600 ft.; and also when the single load of the bucket exceeds 6 cwt. In general, the great advantage of this system consists in relieving the traction-rope of the weight of the loads, so that on comparatively level lines the tension upon the traction-rope is but little more than the tractive force required to move the load. In fact on level and regular ground the motive power necessary to haul one ton can be assumed at $\frac{1}{8}$ H.P. per mile. As a rule, these systems of transportations are very convenient in mining where large quantities of material must be hauled every day, and where the country is usually so hilly that any other means of hauling will be far more expensive. But they are never used and are not convenient in the excavation of earth for public works.

This system of cableways is economical in wear and tear, but the first cost is greater than in the other two already indicated. This will, however, be very efficient when the daily quantity of material to be transported is large, because in such cases the cost per unit of volume of the material will be greatly reduced. The cost of working a cableway of the Otto system of the capacity of 500 tons per day is about 1*d.* per mile, and including repairs, interest on capital, and depreciation, about 1¼*d.* per ton per mile. For another Otto ropeway at Esch in Luxemburg, which is three miles in length and transports 300 tons of ore per day of ten hours, the cost of transport including all expenses, viz., wages, repairs, interest on capital and depreciation, works out to only 4½*d.* per ton or 1½*d.* per ton per mile.

All these systems of ropeways so far reviewed have an inherent defect, says Mr. S. W. White, of the firm R. White & Sons, of Widnes, Lancashire, England, a defect that so far has largely militated against their usefulness. They must all go in a direct straight line from end to end, and if a corner must be turned, an angle-station, with one or two attendants, has to be provided. And further, the carrying-rope used (whether on the single- or double-rope principle) has to be long and strong enough to carry the weight of the whole aggregate load on the line at once, less a

certain percentage for saddle friction, and consequently ropeways have only been able to carry relatively small loads with small output. To avoid these inconveniences Mr. White has patented a system in which are used separate ropes for every span, so that heavy individual loads of 1 or 2 tons each can be easily carried, and the loads can also turn corners at every span if necessary, and without any extra cost.

Fixed Cable Track with Endless Hauling-rope. — The method of hauling materials by means of a fixed rope in which only one carrier is employed hanging from it and moved along the cable by means of a thinner hauling-rope, is more important to engineers and contractors, being the only system used in the ordinary excavation of earth required for the execution of public works. This method was at first introduced by Mr. W. Carrington, and afterward greatly modified and improved. It will be convenient to study these cableways in two separate groups. The first includes those acting as a simple means of transportation as originally derived by Mr. Carrington, and the second includes cableways operating as hoisting- and conveying-machines. The cableways of the first group find convenient employment in the industries, but those of the second that are now extensively used on public works.

The cableways of the first group are composed of one single fixed rope to which one carrier is suspended and is moved back and forth by means of an endless hauling-rope. This endless rope is commanded by an engine provided with reversible motion, so that the direction in which the carrier runs may be changed by the operator. The fixed rope is supported on posts at intervals of about 300 ft., and the hauling-rope is carried on pulleys fitted with guide-bars, placed in the center of the post over which the carrier passes, the posts being arranged so as to allow of the carriers passing through them. The return hauling-rope is supported on an outside pulley mounted on an arm of each post. The hauling-rope is attached to the carrier-head by a peculiarly shaped pendant which causes it to pass under the saddle transom.

With this system, Mr. Carrington says, inclines up to 1 in 1

or even steeper can be worked, spans up to 2000 yds. may be operated, and loads up to 5 tons may be dealt with.

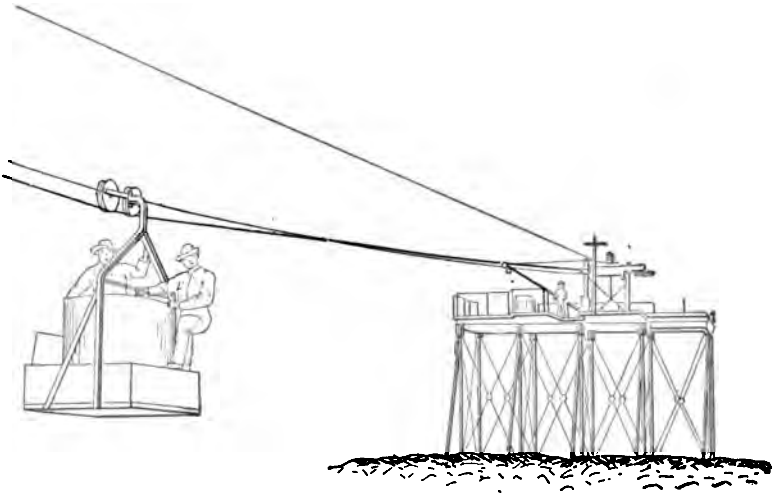


Fig. 110.

Fig. 110 shows the general arrangement of this kind of cableway, indicating the end tower and the single traveling bucket supported by the fixed rope and carried along by the traction rope. Fig. 111 shows the post with fixed rope in position when the carrier is not passing.

Fig. 111.

The single fixed-rope cableways used in public works have only one span and, besides the hauling-rope which moves the carriage back and forth, are provided with a second rope by means of which the load can be raised or lowered at the will of the operator. These cableways are really hoisting- and conveying-machines, and are found in great numbers on the market with different names, as the Floory, the Carson, the Roebling, the Locke & Miller, etc. They are all founded on the same principle,

but vary greatly in their details; some are very simple, as the Carson trenching-machine, and others quite complicated, as the Locke & Miller; and in order to avoid useless descriptions, only these two types of hoisting- and conveying-machines will be illustrated here.

The Carson trenching-machine takes its name from Mr. Howard A. Carson, the chief engineer of the Boston Transit Commission. It is called a trenching-machine, because it was designed by Mr. Carson while he was general superintendent of the sewers of Boston, for the hoisting and conveying of materials to and from the bottom of trenches. The Carson cableway is made up of a track-rope fixed to the ground and supported by means of two A frames. The track-cable, whose diameter varies from 1½ to 2½ ins. in diameter, is fixed to the ground by means of what are commonly called the dead men. These consist of wooden beams from 6 to 8 or even 10 ins. in diameter, and around which is looped the rope in the manner represented in Fig. 112. To

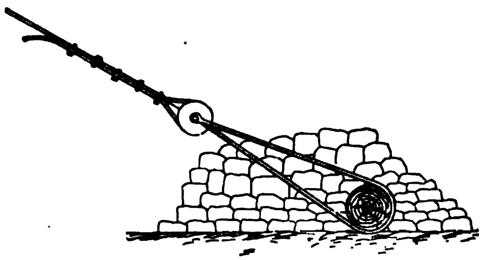


FIG. 112.

prevent any movement of the beam and consequently of the attached rope, the ends of the beams are buried under piles of stone or other material. The A frames supporting the track-rope are located at the extremities of the system 150, 200, and even more feet apart. They are called A frames on account of their similarity to the letter A. They are made up of square beams 6×6 ins. or 8×8 ins., and in the manner indicated in Fig. 113. On top of the cap-pieces there is an iron saddle for the support of the cable. At the front frame, just underneath the cap-piece and between the two inclined beams of the frame, there are three

pulleys—one for the hoisting-rope and two for the hauling-rope. At the rear frame there is an inclined sheave for the return of the

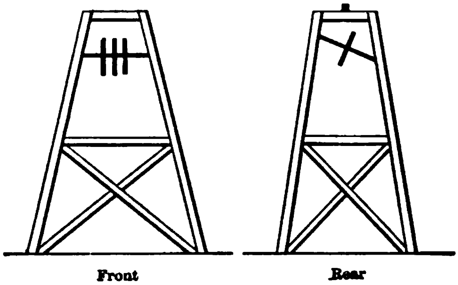


FIG. 113.

hauling-rope; it is placed in an inclined position in order to allow the returning hauling-rope to pass on one side of the carriage. The front frame is connected with a wooden platform upon which is located the boiler and a double-drum reversible engine for operating the cableway.

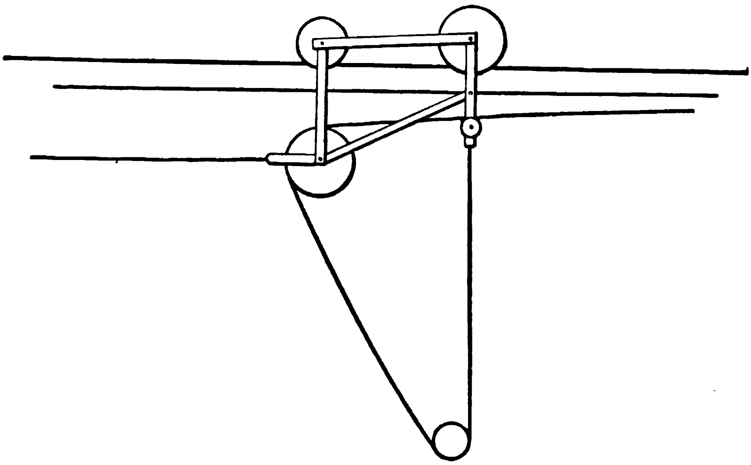


FIG. 114.

The carriage (Fig. 114) is composed of two grooved wheels for running on the track-cable; the front wheel is the larger, and they are connected by means of iron bands. Below the smaller wheel of the truck, by means of two vertical iron bands, is sup-

ported the large hoisting-sheave with a very small one between them for the support of the hauling-rope, while below the larger front wheel of the truck there is a small sheave for the support of the hauling-rope.

The hauling-rope is attached to the front end of the carriage, and passing over one of the sheaves of the head frame goes around one of the drums of the reversible engine. It then passes over a second sheave of the head A frame, and through the carriage over the two smallest wheels, thence over the inclined sheave of the rear A frame, and returns and is tied to the rear end of the carriage and near the hoisting-wheel. One end of the hoisting-rope is tied to the front of the carriage, and it supports a fall-block to which the bucket is attached, and then passing over the large hoisting-wheel of the carriage returns over a sheave at the head-tower and around the second drum of the hoisting-engine. By turning either way the first drum of the engine, the carriage is moved back and forth along the rope trackway, and by loosening the rope commanded by the second drum the fall-block is lowered, and consequently the skip or bucket attached to it can be lowered to the bottom of the trench. By reversing the drum the attached bucket is raised to a convenient height, so that it may travel along the ropeway without any interference. Thus Carson's trenching-machine is really a hoisting and conveying apparatus.

The efficiency of the machine is assumed at 600 cu. yds. per day, and since the running expenses of the apparatus can be assumed at $12, the cost of hoisting and conveying, a unit of volume of the excavated earth is 2 cents per cu. yd.

Carson's trenching-machines have been extensively employed in the construction of the New York rapid-transit railway, and all the subcontractors have unanimously declared that it is the simplest and most economical device for handling earth and rock from the bottom of trenches to the ground-surface.

This simple hoisting and conveying device cannot be employed with spans longer than 200 or 300 ft. For longer spans it is necessary to support both the hoisting- and hauling-rope, and for such

a purpose the fall-rope carriers are introduced, and since these are employed at some distance apart there is used another rope which is called a button-rope. One of the most complicated but extensively used cableways of this type, which on account of its particular construction can be used with spans of even 2000 ft. and for carrying weights of even 5 tons each, is the Locke-Miller cableway, whose description is given below.

The Locke-Miller Cableway.—The following is a description of the Locke-Miller patent cableway manufactured by the Lidgerwood Manufacturing Company of New York. The main cable is usually of steel wire, and is suspended from towers or A frames, which may be from 200 to 1500 ft. apart, and the ends are securely anchored. This cable is used on a trackway upon which travels a carriage supporting a load, which may be either raised or lowered by means of a fall-block. Three additional ropes are employed in this style of cableway, one for moving the carriage along the main cable, and called the traversing- or endless hauling-rope; another which commands the fall-block and is used for hoisting the load, and is called the hoisting- or fall-rope; and a third or button-rope, introduced in order to place the fall-rope carriers from the carriage at regular intervals along the cable.

FIG. 114*a*.

The power for operating this cableway consists of a specially constructed engine represented in Fig. 114*a*. This is provided with double cylinders, reversible link-motion, and friction-drums and brakes. Both drums are of precisely the same diameter, but

one is narrow and of a curved form to receive the traversing or endless rope, and the other drum is wider and spirally grooved for the hoisting-rope. The endless hauling-rope is turned three or four times around the drum so as to secure sufficient friction to keep it from slipping in a direction opposite to the one in which the drum is turning, and this hauling-rope, after passing over the sheaves on top of the A frames or towers, is made fast to the front and rear of the carriage. As the engine is made reversible by turning the drum forward or back, the carriage is pulled along the fixed cable-track in either direction at will. The hauling-rope attached to the carriage is supported by the fall-rope carriers.

The hoisting-rope goes from its drum on the engine to the carriage, and there it connects with the fall-block, usually by a three-part purchase and in the manner indicated in Fig. 115, in which are clearly shown the various ropes of the Locke-Miller cableway. The hoisting-rope is supported by a system of fall-rope carriers, upon which the successful operation of the whole cableway depends. These carriers are of wrought iron and are made light and strong and are provided with suitable wheels for the support of both the hauling- and hoisting-ropes. They ride on the horn on front of the carriage until they are displaced by means of steel buttons located on the button-rope, so that each button will pass through every carrier except one, and this will be pulled off the horn of the carriage. As these buttons are located at regular intervals along the button-rope, it is evident that at each button a carrier will be displaced from the horn of the carriage as this is passing along. In this way both the hoisting- and hauling-ropes are supported all along the line. When the carriage moves in the opposite direction, the carriers will be picked up by the projection of the horn on the carriages as fast as they are reached.

Fig. 116 shows the special form of carriage designed for the operation of the Locke-Miller cableway. It is made in a substantial manner of wrought iron, and yet it is comparatively light. The running-wheels are of cast iron with deep flanges, and have anti-friction bearings so as to run as easily as possible on the cable. The hoisting-wheels are also of cast iron, and of

large diameter, to reduce the wear on the hoisting-rope, and also to enable the fall-block to lower as freely as possible. The fall-block is specially constructed for cableway work, has wrought-iron sides and anti-friction bearings, and is made as light as com-

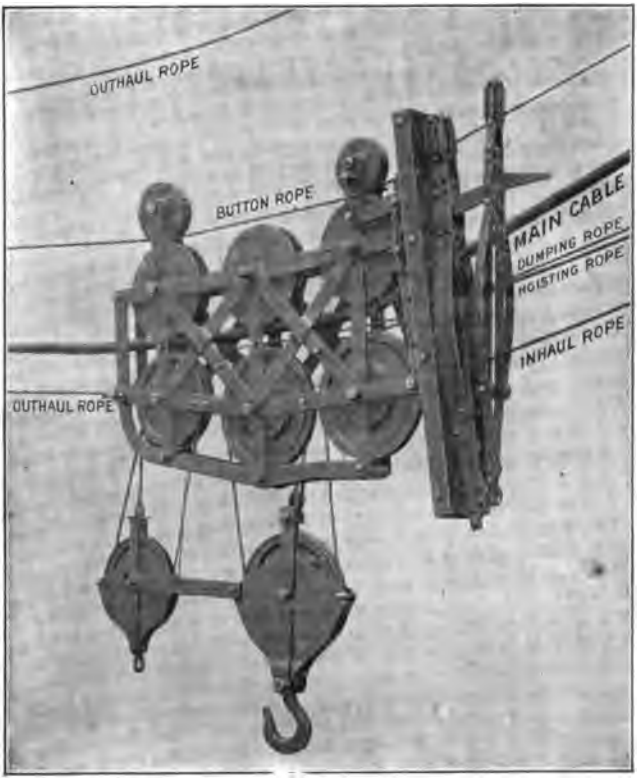


FIG. 115.

patible with strength and overhauling the hoisting-rope, so that it may be easily handled. The purchase used is generally three parts, but it may have one, two, four, or even more parts if necessary.

The entire operation of this cableway is under the absolute control of the engineer, who with a little practice can work the cableway so accurately as to even lay cut stones with perfect ease. It is thus well adapted for the construction of dams, long walls, breakwaters, etc. It is very valuable in public works for

the economical handling of materials, and it is of special value in the excavation of rock, since it is out of the reach of a blast. This cableway is used with great success in all kinds of quarry work, where loads of 15 tons are picked up in the quarry and landed

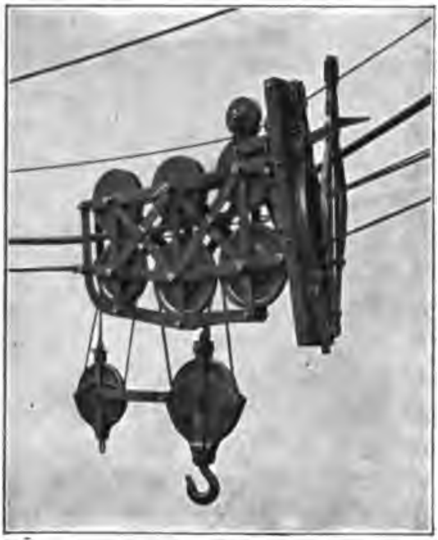


Fig. 116.

on cars with perfect ease and at a speed hitherto unknown. With a Locke-Miller cableway, 1350-ft. span, designed for a 6½ ton load, with a steel cable 2½ ins. in diameter, loads of from 7 to 8 tons weight were easily handled at a speed of 600 to 800 ft. per minute.

The daily cost of working the Locke-Miller cableway is given by the Lidgerwood Manufacturing Company, the builders, as follows:

3 men to operate the conveyor, at $1.50	$4.50
1 engineer, at $3.50	3.50
1 fireman, at $1.75	1.75
1 signalman, at $1.50	1.50
Coal	4.00
Oil and waste	.50
	$15.75

To this amount should be added the wage of a laborer employed to oil and clean the apparatus. This, however, is exclusive of the cost of labor for loading the buckets, an item which cannot be charged to the conveyor. On Section 8 of the Chicago Drainage Canal a total of 344.175 cu. yds. of rock were removed by this kind of cableway acting as a hoisting- and conveying-machine. The cost was 3.56 cents per cu. yd.

Movable Cableways.—A great advantage in connection with this system of ropeways, in which only one carrier travels back and forth on a fixed rope moved along by an endless hauling-rope, is that the towers supporting the rope can be placed upon wheels and consequently the whole machine can be moved in a direction either parallel or perpendicular to the rope. In such a case the two ends of the fixed carrying-rope, instead of being held in position by dead-men, as indicated above, are firmly fixed at the extremes of the platforms supporting the towers. The Carsons trenching-machine and other similar simple cableways, when moving in a direction parallel to the carrying-rope, are very convenient in the excavation of trenches and for laying pipes under city streets, and when moving in a direction perpendicular to the carrying-rope are very convenient for the excavation of canals, roads, and other similar structures having considerable width and much greater length.

In the excavation of the Chicago Drainage Canal it became necessary to use some device by which the material could be rapidly hoisted and conveyed to the spoil-bank and yet that was sufficiently portable to travel along the banks as fast as the work progressed. Accordingly the Lidgerwood Manufacturing Company patented a traveling cableway which was very advantageously employed in various sections of that important work. Notwithstanding that *Engineering*, Vol. LXIII, p. 271, claims that the invention is due to a French engineer named Pluchet, who about half a century ago patented a cableway for canal construction which traveled along the banks after the manner of the Lidgerwood apparatus, it is highly improbable that the original system

was ever used, and credit is due to the Lidgerwood Company for the first application of this system.

It was a cableway of the type being considered, having one fixed carrying-rope and provided with only one large bucket, which could be moved back and forth by means of a hauling-rope, and also raised up or lowered by means of a hoisting-rope. The span of this cableway was 700 ft. and the load to be carried varied from 5 to 8 tons. The head tower was 92 ft. high and mounted on a car 44 ft. wide and 108 ft. long. The tail tower was 72 ft. high and mounted on a car 37 ft. wide and 82 ft. long. These cars were supported on a suitable number of railway wheels of standard gauge and each car ran on three tracks. In order to insure proper stability these cars were heavily ballasted with stones on the outside. The tail tower was located close to the channel, while the head tower was beyond both the channel and spoil-bank, as indicated in Fig. 117. The cars were moved back

FIG. 117.

and forth on the trackway by means of ropes commanded by two small winch-engines.

The cableway was of the ordinary Locke-Miller type and perfectly identical to the horizontal fixed cableway described above, the only exception being the aerial dump by which the loaded skip was dumped while moving through the air and passing above the spoil-bank. This is clearly indicated in Fig. 118, taken from an instantaneous photograph. This operation was obtained by means of an auxiliary rope running from the hoisting-drum of the engine over the carriage, and attached to the third

chain of the skip. As the carriage approached the head-tower this rope was drawn in at a higher rate of speed, thus raising the end of the skip and spilling the load entirely, at will of the engineer and while the carriage was in motion. The engine was then instantly reversed and the carriage went back over the canal,

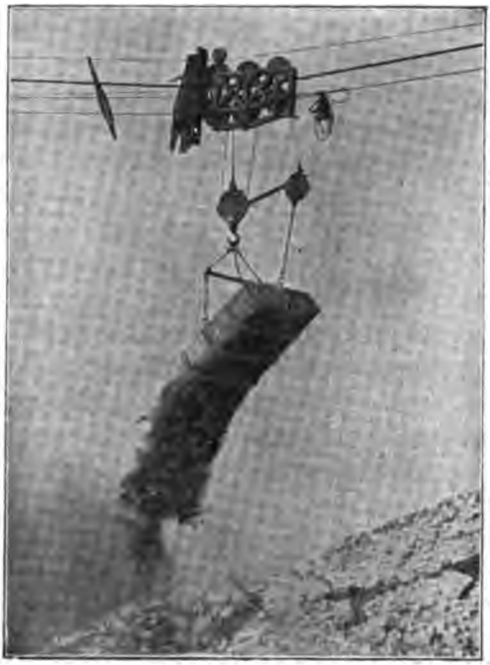


FIG. 118.

the empty skip which had resumed its horizontal position was lowered and unfastened, and the chains hooked to a full skip.

The daily capacity of this movable cableway was about 600 cu. yds. of rock per day, and the average distance of the haul was about 300 ft. The skips contained about 2 cu. yds. of stone. Single rocks of nearly 4 cu. yds. have been easily handled. The cost of hauling the material by means of movable cableways on the 8th Section of the Chicago Canal was 3.56 cents per cu. yd.

Inclined Cableways.—All the various systems of cableways described are generally employed for horizontal roads, although

they are also used on inclined lines; but when the inclination is too great cableways of special construction are usually employed. Inclined cableways can be used either as a simple means of transportation, or as a hoisting- and conveying-machine; the former are known as "shoots," and the latter are called inclined cableways.

Shoots.—Shoots, Mr. Carrington says, consist of one fixed rope placed on an incline on which the carriers, from which the loads are suspended, are allowed to run down uncontrolled one at a time. It is a system of a simple nature, and is used for the transport of undamageable goods. It consists of a light wire rope stretched between two points, the elevation of one being considerably above that of the other. On this, loads from 1 cwt. to 4 cwt., hanging from a runner carrying one or two wheels, are allowed to run down uncontrolled. At the lower end brushwood, or other convenient means, are provided to absorb the force produced by the running load when it arrives at the lower terminal. This can be considerably lessened by regulating the sag of the rope where the section of ground will admit, so as to reduce the speed of the runner with its load as it approaches the lower terminal. Such a type of cableway is largely used for the carriage of firewood, coffee, or other like materials. Spans can be made without support up to 7000 ft., and all that is required for fixing the rope is a good anchorage at the upper end, and another with a tightening-gear at the lower end. Ropes for this purpose up to 3500-ft. spans are used, made in the form of a strand; above this, in order to obtain the necessary strength with a moderate size of wire, ropes are used consisting of several strands formed each of several wires. The runners have wheels of small diameter, and are made as light as possible in order that, after 50 or 100 loads have been delivered, the empty ones may be carried up to the upper end for a further delivery of material.

Inclined Cableways.—The inclined cableways used as hoisting- and conveying-machines are similar to those employed on horizontal lines, as the Carson, the Floory, the Locke & Miller, etc., with the difference that the two towers supporting the main

cable are not at the same level. On account of the peculiar form of the catenary curve of the main cable, it is necessary to introduce some arrangements for holding the carriage at the required point, so as to lift the load when the resistance to travel up the cable is less than the strain in the hoisting-rope. This is obtained by means of a specially constructed carriage, known as the Harris-Miller patented inclined cableway, constructed and controlled by the Lidgerwood Manufacturing Company, illustrated in Fig. 119. The carriage is provided with hooks and the main cable with fixed stops. In operation the carriage travels down the cable by gravity until it reaches the stop which engages the hook and

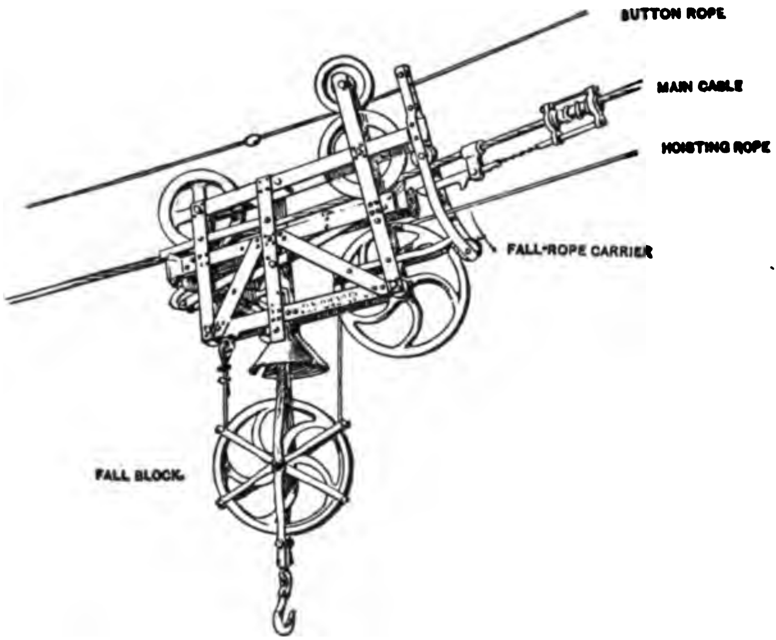


FIG. 119.

releases the fall-block, which descends to the ground to get the load. The fall-block with the attached weight is then hoisted until the carriage is reached. The arm of the fall-block then enters the carriage and is hooked fast, releasing at the same time the hook connected with the stop, thus permitting the carriage to travel

up the incline. On reaching the top of the incline the carriage engages the fixed hook, and at the same time the arm of the fall-block is released and the load may be lowered. To descend again the fall-block is hoisted to the carriage, and the arm entering it is locked fast while the fixed hook which holds the carriage in position is released by means of a hand-rope.

On these inclined cableways there are only three ropes instead of five, as in the Locke & Miller cableways; these are the main cable, the button-rope for the release of the fall-rope carriers, and the hoisting-rope. Also the carriage is much simpler, and is designed with special reference to lightness and strength. It is made of wrought iron, and the locking mechanism is of steel castings. The wheels for the hoisting-rope are of large diameter. Fall-rope carriers are of wrought iron, and their function is to support the fall-rope as the carriage descends the incline. They travel on the special horn or projection at the rear of the carriage, and when they reach the buttons their further progress is prevented and they remain each at its corresponding button, and support the fall-rope, until the carriage in returning takes them and carries them up the incline again. The fall-rope carriers do not interfere in any way with the automatic locking mechanism of the carriage. On very long spans a series of carriers are used, but up to 250-ft. span only one carrier is required. The load for this inclined cableway is 3 tons or less.

CHAPTER XVII.

TRANSPORTING EXCAVATED MATERIALS BY TELPHERAGE.

In the aerialways just described, the carriers containing the materials are moved by ropes. Telpherage is a system of transporting materials on aerialways, where the carriers are moved by electric motors. Telpherage was invented by Prof. Fleming Jenkins of Edinburgh, Scotland, and the name given by him was derived from the Greek words τελε and φερω; *tele* means far, and *ferro* means to bear or carry. Therefore telpherage means far carrying.

According to this method, the carriers travel along the trackway by means of a truck composed of two wheels arranged in the same way as those employed in cableways; and they are similarly suspended from the truck. The trackway may be composed either of rigid beams or cables, and as a rule two trackways are employed—one for the travel of the loaded cars, and the second for the return of the empty ones. This system can be compared with the double-rope system of cableway already described, the only difference being that while in the former the hauling is done by means of a special rope, here instead it is performed by motors located on all the cars or simply on a few motor-cars.

The electric current is distributed in the manner indicated in Fig. 120. Several carriers are connected together so as to form a train, and the electric motor is placed at the center. The cable does not form a continuous conductor for the current, but is divided into sections of the same length as the train. Each section is separated from the two adjacent ones, and they are connected with those in front and back in the manner clearly shown in the diagram. According to this arrangement there are two wires

carrying the electric current which cross each other at the extremities of every section. Each section of the rope is consequently charged with a different kind of electricity. The length of the train is so arranged that its two extremities will always be on two different sections of the rope, in such a manner that they close the circuit of the current. When the rear end of the train leaves one section which is charged with positive electricity, to enter the successive which is negative, the front end of the train that was running on a section of the rope charged with negative electricity, will enter the successive one which is positive. Such an inversion of the current does not change, however, the direction

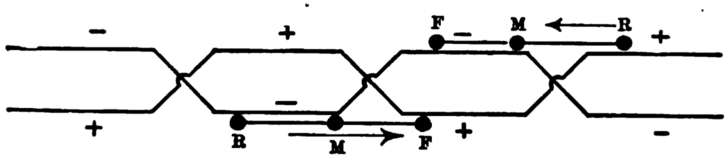


FIG. 120.

of the motor. Consequently a train which travels automatically over one rope is never interfered with by the trains traveling either in the opposite direction along the parallel rope by following trains in the same direction and with little headway.

Several systems of telpherage have been devised on this principle. In the Jenkins, Ayston, and Perry's telpher the trackway is formed by two parallel wire cables supported by posts, and with the interruptions arranged in the manner indicated in the diagram. The carriers move along the trackway, being suspended from a truck, which is composed of two small wheels. The motor is connected to the electric circuit by means of the two wheels at the front and rear end of the train. The motor communicates movement to the wheels of the car by means of belt transmission. The inventors have devised also a scheme for preventing one train from reaching another by means of an additional section, which is open or closed automatically by the cars, and when a train is on this dead section the circuit is broken off and the following train will automatically come to a sudden stop.

This telpherage system was successfully employed at Glinde on a line one mile long, which is still in operation. The motor-car occupied the center of a ten-car train, so that five cars were in the front and five at the rear of the motor-car. The capacity of the cars is 100 lbs. each; and they are kept at the same distance from one another by means of connecting-rods.

Somewhat different from the system just described is the one used at present and controlled by the United Telpherage Company of 20–22 Broad Street, New York, with branches in all the principal cities of the world. The following description is taken from a paper read by Charles M. Clark at the meeting of the American Institute of Electrical Engineers, New York and Chicago, April 25, 1902.

In regard to the construction of the telpherage system, Mr. Clark says that it may be stated that the track is made of cable either of standard or lock-coil wire, which latter has a strength approximating 95 per cent. that of the solid bar, or else solid rail, either of flat, girder, or bulb type. The cable-tracks are supported every hundred feet, provided it is convenient to erect poles or structures. Where there are deep ravines the span is made to correspond with the distance, and can be made of any reasonable length. In addition to the track-cable, upon which the telpher runs, there is also what is known as the suspension cable, to which the main cable is suspended by means of hangers to prevent excessive sagging. The sizes of the cable, hangers, and brackets vary, depending upon the weight which comes upon each individual span. The support is either made of simple poles with a bracket, or of what is known as A construction, or of ordinary cross-bents. Cable construction costs less than solid rail, except where there are many switches, in which cases the prices of solid rail and cable approach each other. In general, for straight lines, cable is recommended except where the weight is excessive.

In solid rail construction the supports are ordinarily placed 16 to 20 ft. apart; longer spans are used if it is not convenient to erect supports. On long spans, the track consists of a girder-rail with the track above it. Running parallel to the track-rail,

either above or at the side, and depending upon the amount of headroom, are stretched one or more trolley-wires; one wire, if the track be used as a return. If, however, it is desired not to use the tracks as a return, or to use alternating current, two trolley-wires are employed.

According to the construction, telphers are divided into three distinct classes—center-bearing, side-bearing, and alternate-bearing. The center-bearing has two motors, one on each side of the track; the side-bearing (Fig. 121) has both motors on the same side, and the alternate has one motor upon one side of the track, and the other motor upon the other side, but not upon the same shaft.

FIG. 121.

The motors are water-proof and dust-proof, and are compound wound for automatic work. When a telpherman goes with the telpher, the series winding is employed. There is also used a special coil to give greater torque when starting. The telpher is placed above the track, thereby keeping the motors from injury, while there is also no danger of their coming in contact with the carriers or being otherwise injured.

The hoist (Fig. 122) is suspended below the telpher, or sometimes from a trailer drawn by the telpher. Special effort has been made in the later designs of hoists to use as little headroom as possible. It was deemed best at first to combine the telpher and hoist all in one, but there were so many cases where it was necessary to use the telpher alone without the hoist, and also where it was advisable to put the hoist on the trailer instead of on the telpher, experience has shown it to be better to have the telpher and hoist two separate pieces of apparatus.

Two distinct types of brakes are used on telphers, either hand-brakes or solenoid-brakes, both of which are arranged to apply

pressure to the wheels or to grip the track. In regard to the solenoid-brake it is only necessary to explain that it works automatically, the solenoid being placed in series with the armature. A spring normally holds the brake on the wheel or the track. If, however, from any cause, the amount of current passing through the solenoid is reduced, whether by means of external resistance or by reason of the additional counter-electromotive force generated by the armature due to running at a high speed, the solenoid becomes weakened and the brake is applied. An air-cushion is arranged so that the brakes will be applied gradually.

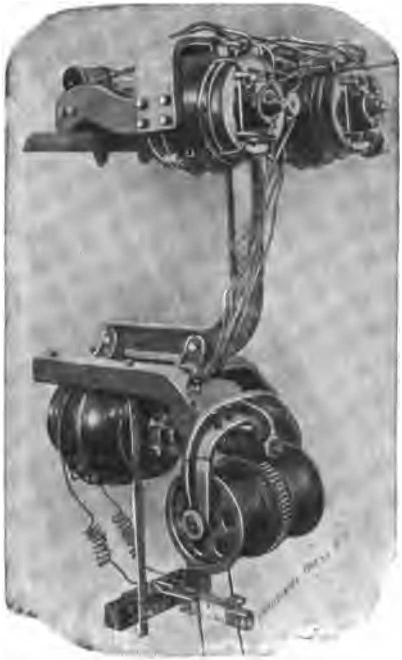


FIG. 122.

It is often advisable, where a large amount of material is to be carried, especially over one track, to use trailers. These consist generally of a two-wheeled truck, below which is suspended a bucket or other suitable form of carrier, or even the hoist, as the case may require. It is customary, where a larger amount of material is to be carried, to arrange a long train carrying as much as ten tons. The order of procession is first a telpher with four or five trailers, then another telpher and four or five trailers, and a telpher at each end. The placing of these telphers at intervals greatly adds to the traction, while the distribution of weight over the whole span, or over two or three spans, enables much lighter construction to be used for the same capacity.

In automatic lines it is necessary to provide appliances whereby it is impossible for an unskilled operator to injure the telpher. In order, therefore, to provide for contingencies, a "dead section"

is placed at each end of the line, the middle of the line being generally left alive. Upon closing a spring-switch, the dead section is energized so long as the operator keeps his hand on the switch, which is generally only a few seconds, during which time the telpher passes to that portion of the line which is always alive. When it reaches the other end it comes upon the dead section and then either shoves down of its own accord, or else a mechanical or solenoid-brake is applied. The telpher then passes under the reversing arrangement and it is therefore reversed either with no current in the line, or else with a high resistance. If the telpher is at the further end of the line, the operator at the near end, by closing a switch, can bring it back to him. The dead sections at the end of the line, which only have current so long as the hand is held upon the spring-switch, render the line as safe as possible against the telpher coming in contact with the terminal posts. An automatic block system prevents collision of telphers.

In regular service the speed varies from 300 to 800 ft. per minute up to 20 miles per hour, or even more when required. The lower speeds are used when the lines are short, and where there are many curves, particularly for factory and foundry work. For lines running across the country a speed in excess of 20 miles per hour can be obtained, but with the higher speeds the cost of the construction increases, certain special devices being necessary.

Although the amount of power can be easily figured out, yet it is somewhat in the nature of a surprise when we consider that to carry half a ton on a level track, at a speed of 6 miles per hour, much less than a horse-power is required, including all losses. The absence of gearing, the motors being attached directly to the driving-wheels, gives the highest efficiency possible, as well as freedom from noise. The actual power consumed at 6 miles per hour for 1000 lbs. on a level is only 0.16 H.P. It is therefore seen that ample allowance is made for losses and extra weights not provided for in the load, such as down-comes, buckets, or carriers. The power required increases greatly with the grade, and when this reaches certain limits it is deemed advisable to use gears in order to reduce the weight of the motors.

An important feature in telpherage is the capacity of the line. There are two factors of special importance in relation to the capacity of the line: first, the speed; and second, the number of telphers and trailers. The line can be laid out with one telpher and a few trailers. More telphers or trailers may be added, and, if upon a single line, coupled in long trains. If it is desired to increase still further the capacity, the line can be made double; while, if desired, the carriers may also be made continuous, so as to take boxes and barrels, or any other material, as fast as they can be delivered to the carriers of the telphers and trailers.

The flexibility of telpherage in regard to capacity is wonderful, and is a most important feature. In fact, it may be said that there is practically no limit to its flexibility. It is recorded even a capacity of 250 tons per hour carried on a line half a mile long. There is no other means of transporting materials which can be operated so economically, cheaply, and in so thoroughly satisfactory a manner as telpherage.

Telpherage has been very successfully employed as a means of carrying materials from one part to another of large and extensive factories, in carrying coal and ashes in power-houses, in conveying the products of farms and plantations, and in the transportation of ores in mining. In general, it may be said that wherever material is to be carried to a distance, there is no power so flexible, so economical in first cost of installation, costing so little for power or the expense of maintenance, and with such great capacity, as telpherage.

Notwithstanding the United Telpherage Company states that this method of transportation of excavated materials can be advantageously employed in the construction of roads, railroads, and canals, it has not yet enjoyed the favor of the engineers and contractors. The writer has no knowledge that it has ever been employed on public works, with the exception of an aerialway provided with an electric motor which was used on some sections of the New York rapid-transit subway. It was invented by Mr. W. F. Brothers of New York City, and can be considered among the telpherage systems more properly than under cable-

ways, because the single skip is hoisted and moved back and forth along the cable-track by means of electric motors instead of being moved by hoisting- and hauling-ropes. This special electric cableway is illustrated in Figs. 123, 124, and 125, and was described in *Engineering News* as follows:

One of the unique features of this cableway is the manner in which the main cable is supported. It is fixed at either end to an inclined A frame, which is free to swing up and down, and is loaded by a weight hanging at its outer end. The cables supporting the weights on the A frames are of such a length that both weights cannot rest upon the ground at the same time. The proper magnitude of these weights is known from the deflection of the main cable when the latter is hanging freely.

When the carriage travels away from one of the shears, the main cable sags and the weight at that end rises, but when the carriage returns the change in the inclination of the main cable at the point where it is attached to the shear is sufficient to give the weight a preponderance, and it sinks.

This may be understood from the triangle of forces in Fig. 123. Let *AB* be the force exerted by the weight hanging verti-

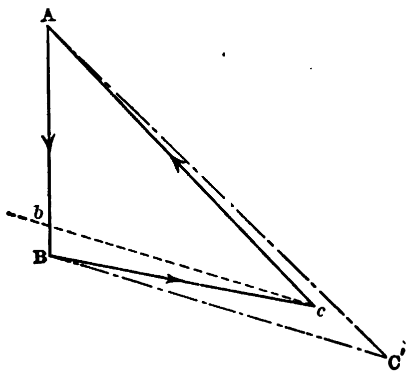


FIG. 123.

cally; it is constant in magnitude and direction. *BC* will be the tension in the main cable, and *CA* the thrust in the A frame. If the inclination of *BC* now changes to *bC*, *AB* will be greater

than the resultant of bC and CA, and will pull the end of the A frame down until a new position of equilibrium is reached, as indicated by the triangle BCA. The work done by the falling weight is expended in lifting the load on the carriage so that the motor is assisted a certain amount as it approaches the A frame. And also on account of the automatic lowering of the latter there is less total work to do. An important advantage of this arrangement is that the skip may be brought out beyond the point of support of the A frame, as can be seen in Fig. 124. The machine

FIG. 124.

is operated by electricity, and the electric motor is mounted directly on the traveling carriage. The operator rides on the carriage and controls the operations of hoisting, conveying, dumping, and lowering by a system of switches. The electric motor which performs the work of hoisting and conveying on the carriages is of 15 H.P. capacity, and is provided with the usual switches, rheostat, and other controlling devices. A reversing-switch enables it to drive the carriage in either direction. Upon the end of the motor-shaft is mounted a friction-pulley which may be caused to engage and drive either of the two large wood-rimmed pulleys to be seen upon the farther side of the carriage in Fig. 125. The shaft of the upper large pulley carries a pinion which engages

with teeth on the periphery of the two traveling-wheels. The lower wood-rimmed pulley operates by worm-gearing the drums upon which are wound the cables from which the skip is suspended. These drums may be worked independently, and in that way the skip may be dumped. The motor-cars hoist and carry a skip-load of about three tons. The current is led to the motor by a small trolley-wire strung below the main cable, and which may be seen passing over the two small wheels at the side of the carriage. The main cable carries the return current. The main cable would usually be grounded, but in the installation of this system on the Section 11 of the New York rapid-transit, which is here illustrated, a 220-volt direct current was taken from the Edison three-wire system. This necessitates insulators in the hoisting-ropes leading to the skip, which in the present instance are short pieces of manilla rope.

FIG. 125.

The advantage of this cableway is that one man does the work which requires two or more men in other types of trench-machines. Besides, the operator is located close to the skip which is being moved, and he can direct the movements much more easily than when he is located some distance away, as is the engineman operating the common steam trench-machine. Another advantage is that the A frame may be mounted upon wheels. If one is so mounted and the other end of the cable is fixed, the frame may be made to travel about on a circular track, having the center of curvature at the fixed support. In this way a large area may be covered. In a similar manner both frames may be mounted upon wheels running upon parallel tracks.

The work of this machine is given by the inventor and manufacturers at 4 c. per cu. yd. of earth excavated. This machine could be conveniently employed for several purposes on public works. On account of the special arrangement of the A frame just indicated, it is very valuable in the excavation of small distributing reservoirs and of large canals in which the excavated material has to be dumped in some place alongside its edges. One of these machines, with a span of over 100 ft., was used by Mr. John Shield, the contractor for Section 11 of the New York rapid-transit railway. It has given perfect satisfaction in all the points claimed by the inventor, but Mr. Shepard, the engineer for the contractor, states that in the present form it is a little too slow for the handling of earth, while it is the best device that could be adopted in the construction of dams where all the various stones could be set by the operator in a more correct, and also in an easier and quicker manner than with any other means.

Telpherage can be used also in excavating and leveling, in preparing road-beds for railroads, as it is shown in the accompanying diagram (Fig. 126). In such a case the function of the telpher

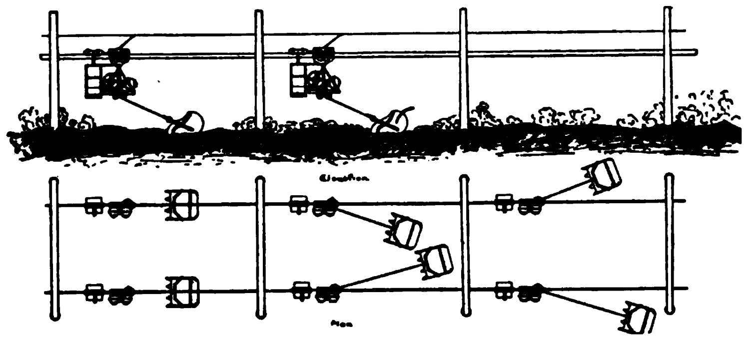


FIG. 126.

is to transport the hoist, bucket, and load. The hoist does the excavating and elevating. The hoist automatically brakes itself either upon the girder-rail or grips the cable as soon as there is any longitudinal strain.

Although the excavation can doubtless be done by means of

telphers, the writer does not know of any instance in which telphers have been employed for such a purpose; while, on the other hand, movable cableways have been used with splendid results. Thus on Section 9 of the Chicago Drainage Canal the excavation of the surface material was made by a large scraper commanded by movable cableway, which was designed and patented by Charles Vivian and controlled by the Lidgerwood Manufacturing Company. It was adapted to deal with soft material, which it did very efficiently, and has been successfully employed since for handling sand and gravel in the excavation of canals and for railroad work where a deep cut and fill adjoin each other.

The Vivian scraper is made of steel $5 \times 5 \times 2\frac{1}{2}$ ft. and having a capacity of about 3 cu. yds. It is filled, conveyed, and dumped by means of ropes moved by an engine located at the rear of the spoil-bank. The ropes are supported by two high wooden towers provided with sheaves and head-tackle. The engine and boiler as well as both towers are mounted on cars in order to follow the work.

The Vivian scraper is operated in the following way: The endless running-rope of the cableway attached to the rear of the scraper is pulled until the scraper stands at an angle of about 45° with the ground. The drag-rope connected to the other drum of the engine is then put into gear, and the scraper will be pulled along. The endless rope is controlled by the brake until the scraper is filled, then the endless rope is slacked off and the scraper hauled to the spoil-bank by the drag-rope. To dump the scraper, the drag-rope is thrown out of gear and the endless rope into gear, upsetting the scraper, which will unload its contents. When emptied the engine is reversed and the endless rope will return the scraper to the cut, allowing the drag-rope to overhaul. The Vivian scraper is operated by three ropes—one $1\frac{1}{8}$-in. drag-cable which drags the loaded scraper, and two $\frac{3}{4}$-in. ropes, one of which dumps the scraper on the spoil-bank, while the other, called the out-haul rope, returns the scraper for another load. These two latter ropes wind on the opposite side of the same drum.

Fig. 127 shows the Vivian scraper loaded and dragged toward

the spoil-bank, and Fig. 128 shows the tail-tower of the scraper as it was used at Massena, N. Y., by the T. A. Gillespie Company, Contractors, for the canal of the St. Lawrence Power Company. In

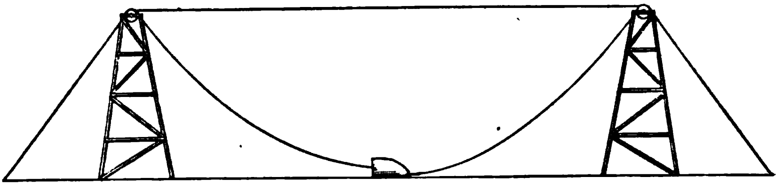


FIG. 127.

the Chicago Canal 500 cu. yds. of earth were often removed in a day, but the quantity of the excavated material chiefly depends upon the quality of the soil and the dimensions of the scrapers. Thus at Massena a greater efficiency was obtained from a scraper 7×7 ft. But it will be safer to calculate at 500 cu. yds. per ten-hour day's

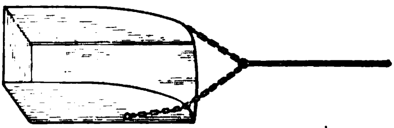


FIG. 128.

work the quantity of loose soil excavated and deposited on the spoil-bank by means of the Vivian scraper operated by a movable cableway. The daily running expenses for excavating and hauling earth by means of the Vivian scraper are given by the daily consumption of coal and the required labor. This consists of a crew composed of 1 engineer, 1 fireman, and 2 signalmen.

CHAPTER XVIII.

CHAINS, ROPES, BUCKETS, ENGINES, AND MOTIVE POWER.

In concluding the description of the various machines used for excavating and hauling it is desirable to devote a few words to ropes, buckets, hoisting-engines, and motive power, which have already been mentioned on several occasions.

In the steam-shovel and crane the hoisting is usually done by means of chains. These are formed of several links inserted into one another at right angles. Each link is made of an iron rod with a diameter varying with the work expected from the chain, but generally from ½ in. to 3 ins. They are bent and welded into the form indicated in Fig. 129. Chains have the defect of wearing off very easily, and this is due to the great friction to which they are subjected in passing over the sheaves and drums; they become weaker and weaker until they are condemned or break. Chains require to be lubricated continuously.

Lately the C. W. Hunt Company of New York have introduced onto the market a laminated chain (Fig. 130) which is notable for strength, economy, durability, and smoothness of action. The links in this chain are flat, are punched from steel especially rolled, and are connected together by means of rivets. By its special construction the chain affords a great resistance to wear and 'oJ', and is articulated so that it can easily be wound around drums. They, however, cannot be wound on a parallel drum, but must be wound in a spiral. Engines are constructed with drums wide enough to wind the laminated chains in a single coil. The advantages of this chain are that there is no danger of breaking without warning, that they are more economical both in maintenance and repairs, and that any man in a half hour's time

can lengthen or shorten the chain or remove any part and insert a new piece in its place. If an examination of the chain is wanted,

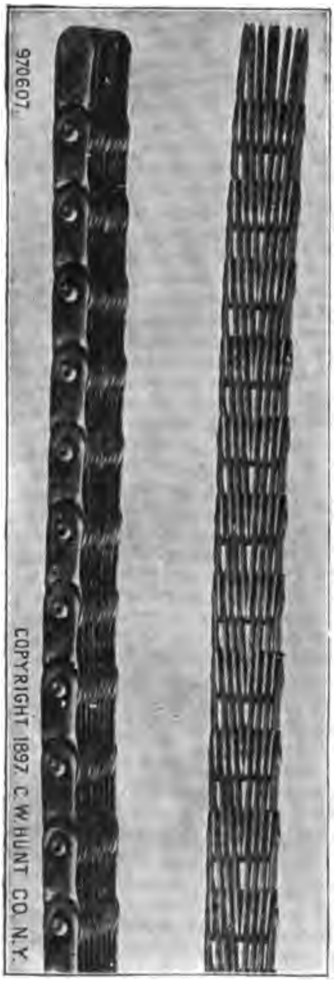


Fig. 130.

Fig. 129.

a rivet-head is cut off and the chain taken apart. A new rivet will immediately make the chain good again.

In the last twenty years ropes have acquired a great importance in engineering and mechanical works, both for hauling purposes

and for transmission of power. They are usually manufactured from two materials—steel or iron wires and Manilla fiber.

Manilla rope is made from the fiber of the Aloe plant, which grows only in the Philippine Islands. The trunk of this plant, which resembles the banana-tree, is closely enfolded by long leaves, and from these leaves is procured the fiber so wonderfully suited to the requirements of rope-making. This fiber varies in length from 6 to 12 ft., and in some leaves attains a length of 18 ft. Its tensile strength is remarkable; official tests at Watertown, Mass., have proved it to be in excess of 50,000 lbs. per sq. in. This great strength, however, is shown only when the fibers are subjected to a longitudinal strain. Transversely, owing to their cellular formation, the fibers are relatively weak. Transmission rope is made with three, four, or six strands; the last two have an inner core, or heart, around which the outer strands are laid. Manilla ropes are used extensively for the transmission of power as substitute for the leather belts, and their description has been taken from the little book on rope transmission published by the American Manufacturing Company, of New York. Although Manilla ropes are very useful to the contractors, yet in connection with excavating and hauling apparatus only wire ropes are used.

Wire rope is made of wires either twisted together or laid parallel to each other. The latter kind is employed only in large suspension bridges, while the former is in general use. There are two forms of wire ropes, flat and round. Flat-wire ropes consist of a number of wire strands which have been laid side by side and sewed together with annealed wire. Round ropes, which are the most commonly employed, are composed of a number of wire strands twisted around a core of hemp or around a wire strand or wire rope. The standard wire rope is made of six wire strands and a hemp core; this arrangement affords the most convenient and compact form, as the strands and the core are practically all of the same size. The core of a wire rope is, as a rule, hemp saturated with tar. It provides little additional strength, but acts as a cushion to preserve the shape of the rope and helps to lubricate the wires. Wire strands are made of wires twisted

together. The number of wires commonly used are four, seven, twelve, nineteen, and thirty-seven, depending upon the nature of the work for which the strands are intended. Ordinarily the wires are twisted in the opposite direction to the twist of the strands in the rope.

The strength of wire ropes depends chiefly upon the material of which the wires are made. As a rule it can be assumed that it is only 80 per cent. of the aggregate strength of all of its wires. Thus the strength of the iron wires ranges from 45,000 to 100,000 lbs. per sq. in.; open-hearth steel from 50,000 to 130,000 lbs. per sq. in.; crucible steel from 130,000 to 190,000 lbs. per sq. in.; and plow steel from 190,000 to 350,000 lbs. per sq. in. The working load is usually calculated at one-seventh of the strength of the wire rope. This factor of safety, however, should be modified for special cases; thus, for instance, elevator ropes seldom have a load of more than one-tenth or one-fifteenth of their breaking strain.

The following table taken from the catalogue of the American Hoist & Derrick Co. gives the tensile and working strength of various ropes:

STANDARD STEEL HOISTING-ROPES.

Six strands. Nineteen wires per strand. Hemp center.

Crucible-steel Quality.			Diameter.	Plow-steel Quality.		
Weight 100 Feet.	Breaking Strain in Tons of 2000 Lbs.	Proper Working Load in Tons of 2000 Lbs.		Proper Working Load in Tons of 2000 Lbs.	Breaking Strain in Tons of 2000 Lbs.	Weight 100 Feet.
26	$4\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{8}$	$1\frac{1}{2}$	8	26
35	$7\frac{1}{2}$	1	$\frac{1}{2}$	$2\frac{1}{2}$	12	35
63	14	2	$\frac{5}{8}$	$3\frac{1}{2}$	20	63
88	18	3	$\frac{3}{4}$	5	27	88
120	25	5	$\frac{7}{8}$	7	37	120
158	33	6	1	9	50	158
200	42	8	$1\frac{1}{8}$	12	63	200
250	52	10	$1\frac{1}{4}$	15	76	250

But wire ropes are not always used to hoist the materials in a vertical direction; they may be employed for hauling materials on inclined planes. Messrs. A. Roebling & Son give the following table in which the strain produced by any load can easily be

calculated. It gives the strain on a rope due to a load of one ton of 2000 lbs. allowing for rolling friction. An additional allowance for the weight of the rope will have to be made.

Elevation in 100 Feet.	Corresponding Angle of Inclination.	Strain in Pounds on Rope from a Load of 2000 Pounds.	Elevation in 100 Feet.	Corresponding Angle of Inclination.	Strain in Pounds on Rope from a Load of 2000 Pounds.
5	$2\frac{7}{8}°$	112	95	$43\frac{1}{2}°$	1385
10	$5\frac{1}{2}°$	211	100	$45°$	1419
15	$8\frac{1}{3}°$	308	105	$46\frac{1}{2}°$	1457
20	$11\frac{1}{8}°$	404	110	$47\frac{3}{4}°$	1487
25	$14\frac{1}{16}°$	497	115	$49°$	1516
30	$16\frac{3}{4}°$	586	120	$50\frac{1}{4}°$	1544
35	$19\frac{1}{8}°$	673	125	$51\frac{1}{2}°$	1570
40	$21\frac{5}{8}°$	754	130	$52\frac{1}{2}°$	1592
45	$24\frac{1}{4}°$	832	135	$53\frac{1}{3}°$	1614
50	$26\frac{1}{3}°$	905	140	$54\frac{1}{2}°$	1633
55	$28\frac{5}{8}°$	975	145	$55\frac{1}{2}°$	1653
60	$31°$	1040	150	$56\frac{1}{4}°$	1671
65	$33\frac{1}{15}°$	1100	155	$57\frac{1}{4}°$	1689
70	$35°$	1156	160	$58°$	1703
75	$37°$	1210	165	$58\frac{1}{3}°$	1717
80	$38\frac{2}{3}°$	1260	170	$59\frac{1}{2}$	1729
85	$40\frac{1}{2}°$	1304	175	$60\frac{1}{4}$	1742
90	$42°$	1347			

In the preceding chapters it has been seen that wire ropes are used in public works chiefly for two different purposes, either for hoisting or as tracks for the aerialways. When used for the latter purpose, they have the same construction as when employed in hoisting, except that the strands contain more wire and the diameter of the rope is usually greater than 1 in. There is no doubt that these wire-rope trackways are liable to wear off very easily, and when the outside wires are worn out, the rope becomes useless and must be discarded. Besides, the twisted wire composing the strands form an irregular surface which results in wear and a great waste of force in hauling.

To avoid these objections a track-cable of special construction has been invented and patented. It is known on the market as the "patent locked-coil cable," and it was so called from the fact that the outer wires are of such shape that they interlock with

each other, as shown in Fig. 131. They present a smooth surface and yet possess sufficient flexibility to be shipped in coils. With this cable are obviated the difficulties resulting from fractured wires and uneven surfaces, while the wearing of the carriage-wheels will be a minimum. This cable is made of steel in lengths of from 800 to 1200 ft., which are joined by patent couplings. They have been especially constructed to be used as trackways in connection with the Bleickert cableway, controlled in this country by the Trenton Iron Company. The track-cables are graduated to the loads and pressure they have to sustain, and, being stationary, possess the great advantage of relieving the traction-rope of the weight of the loads, so that on comparatively level lines the tension upon the traction-rope is but little more than the tractive force required to move the loads.

FIG. 131.

The author has found that these ropes are more expensive in first cost, and also very expensive, owing to the fact that the whole rope becomes entirely useless when only one of the interlocked wires gets out of place. It is true, however, that on account of the smooth surface smaller force is required for hauling the carriage, and both the truck of the carriage and the rope itself are subjected to less wear.

The manufacturers claim that laminated chains never wear out in the ordinary sense of the term. The wear is greater on the working end of the chain than on the drum end. A piece 5 or 10 ft. long is cut off on the working end when it shows wear, and a corresponding length of new chain is riveted to the drum end. Thus the chain advances forward step by step, the engine end being always new and the working end the most worn part. The advantage from this facility of repair or renewal of a worn part by the engineer in charge, together with the great durability in service, makes the expense of laminated chain per ton of material hoisted a sum insignificant when compared with steel-wire rope that must be wholly thrown away if one part is worn too much

for safe hoisting. Laminated chains are built in three different sizes, and their breaking strength and their equivalent strength as compared with wire ropes are given in the following table:

Patent Laminated Chain.	Breaking Strength, Actual Test.	Equivalent in Strength to		
		Iron-wire Rope.	Crucible-steel Wire Rope.	Crane Chain.
No. 835	36,000	1 inch	$\frac{3}{4}$ inch	$\frac{7}{8}$ inch
" 845	46,000	$1\frac{1}{8}$ "	$\frac{7}{8}$ "	1 "
" 860	62,000	$1\frac{3}{8}$ "	1 "	$1\frac{1}{8}$ "

Skips.—The materials which are raised from the bottom to the top of the excavation by means of hoisting- and conveying-machines are placed in receptacles or skips of different forms, varying with the quality of the material removed and the special conditions of the work. The most commonly employed receptacles are scales and buckets for earth, and grabbing-chains for stones.

Scales.—Scales are usually made of wood reinforced with iron. They consist of a square platform 3 ft., sides surrounded by boards $1\frac{1}{2}$ ft. high on three sides. Attached to the platform and in the center of the open side of the scale there is an iron ring, and two similar rings are provided at the top of the rear end of the two parallel side-boards. The scale is lifted by placing in these rings hooks attached to the end of a system of three short chains, which are suspended to the hoisting-block. On account of this arrangement, in hoisting the scale the material that it contains will gravitate toward the interior, thus preventing it from spilling from the open side. The unloading of these scales is very simple. When the dumping-place has been reached, which may be either a wagon, a car, a bin, or the spoil-bank, the scale is lowered so as to relieve the chains of the weight, then the front chain is removed from the ring and the scale is slowly hoisted. Being then attached only by the rear rings this part will be raised while the front will continue to remain at rest, and consequently the material will rush to this side and the scale will empty its contents into the required place.

Scales are subjected to a great deal of wear and, especially when handling rocks, they are easily destroyed. In such a case it is more convenient to have them made of steel, like those used in the construction of the tunnels under Park Avenue for the New York rapid-transit railroad. Here the scales employed were $4 \times 4 \times 2$ ft., and were made of steel and reinforced pieces of iron. The scales were placed on top of platform cars and loaded with the material at the front of the excavation, and hauled to the bottom of the shaft from which they were raised to the surface by means of stiff-leg derricks, and the material they contained was dumped into specially constructed bins.

Scales can also be automatically dumped in the air, as is clearly shown in the reproduction (Fig. 118), from an instantaneous photograph. This manner of dumping was employed in the excavation of the Chicago Drainage Canal, and the scales were attached to the hoisting-rope of the hoisting and conveying cableways stretched across the canal and over the spoil-banks, which were located at one side of the canal. The aerial dump of the scale was obtained by means of an auxiliary rope, running from the hoisting-drum of the engine over the carriage, and attached to the third chain of the skip. As the carriage approached the head-tower and the scale was just above the spoil-bank, this auxiliary rope was drawn in at a higher rate of speed, thus raising the end of the scale and spilling the load at the will of the engineer and while the carriage was in motion. The engine was then instantly reversed, and the carriage went back over the canal, the empty scale which had resumed its horizontal position was lowered and unfastened, and the chains hooked to a full scale.

Buckets.—In connection with cableways, especially for handling stone and other material in sewer and general construction work, steel tipping-buckets are commonly employed instead of scales. These are of the form indicated in Fig. 132. The body of the bucket is made of steel sheet reinforced at the edges; and the bottom is narrower than the top, so that its longitudinal cross-section is in the form of a trapezium, with the longest of its parallel sides on top. A heavy steel handle in the form of an inverted U

is bolted to the body of the skip in such a manner that the skip can revolve around these points of support. They are so balanced that they are top-heavy when full, and bottom-heavy when empty, consequently they are self-dumping and self-righting. To prevent their overturning when loaded, there is a spring-latch on the outside of the bucket, which is opened by a man when the

A *B*

Fig. 132.

bucket has been brought up to the point of dumping. The material then descends along the inclined side of the bucket as in a chute, and once liberated of the load the bucket raises automatically and the latch catches into position again.

The following table, taken from the catalogue of G. L. Stuebner, gives the dimensions of the various steel buckets manufactured. Of these, however, only those marked 125, 127, 129, 130, and 131 are usually employed in excavations for hoisting materials.

From this table it is seen that with buckets of 1 cu. yd. capacity, which are those most commonly employed in earthworks, the height of the bucket is about 30 ins., and consequently the shoveler must make a greater effort in loading a bucket than a scale, since every shovelful must be raised at least over 30 ins. instead of only

TABLE OF SIZES OF TIPPING-BUCKETS.

Size No. of Bucket.	Capacity in Cubic Feet.	Length of Bucket in Inches.	Width over all in Inches.	Depth in Inches.
123	6	33	26	19
124	8	36	27	22
125	10	41	30	24
126	12	42	33	25
127	14	48	33	27
128	18	48	37	29
129	21	48	43	30
130	27	46	46	31
131	27	53	43	29
132	36	58	54	33
132	42	60	58	33

18 ins., as in the scale. Now, since the work of men is limited to a certain number of foot-pounds per day, the smaller the effort required to raise the material for loading the skips the greater will be the efficiency of the work. From this point of view scales should always be preferred to the buckets when no other circumstances require the employment of the latter. Buckets, however, are more lasting and easily handled by the men than scales and for this reason they are preferred.

Grabbing-hooks.—It is too expensive to break into small fragments the large stones detached from the bank by blasting, so that they may be placed either in scales or buckets. It is more convenient to raise these large stones to the surface without breaking them, and this is accomplished by means of grabbing-hooks. These consist of two steel hooks of the form indicated in Fig. 133. Each hook is provided with a ring so that it may slide on a chain made with short links. The chain is attached to the hoisting-rope of a derrick or cableway, and is lowered to the place where the large stone stands, then the laborers place the hooks one opposite the other and in such a way as to grab the projecting parts of the stone. The hoisting-rope is drawn up and the chain pulls the hooks together, so that they firmly hold the stone which will be brought up to the surface and removed to the required place. To detach the hooks, the hoisting-rope is lowered until they are released.

Hoisting-engines have already been mentioned several times in the preceding chapters. These are constructed with drums running in either direction, and are called reversible engines. They can be operated by a single cylinder or two cylinders, and

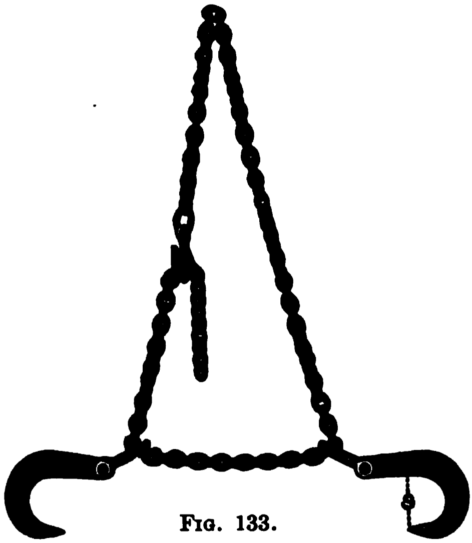


FIG. 133.

are then known either as single- or double-cylinder reversible engines.

The single-drum reversible engine, either with a single or double cylinder, is used in connection with cableways of the Otto, Blieckert, and similar systems, and also for mining purposes, but very seldom in public works. Double-drum reversible engines are very commonly employed in engineering works to operate derricks and cableways. Three-drum reversible engines are now constructed to operate derricks provided with bull-wheels for slewing the boom. Since the single-drum reversible engine, as well as the one with three drums, is not common, only the double-drum double-cylinder reversible hoisting-engine will be illustrated here.

Engines can be operated either by steam or by compressed air. They are now constructed also so as to be operated by elec-

tricity. Since their construction is somewhat different from the ordinary hoisting-engines, it seems desirable to give a description of a double-drum reversible hoisting-engine.

Double-drum Reversible Engine.—The engine is mounted on a cast-iron bed-plate which has two standards for the support of the drum. They can be either cast together with the frame, or securely bolted to the frame, and their alignment is preserved by pins. The cylinder, or cylinders, since the great majority of hoisting-engines are provided with two cylinders, are located horizontally and very close to the rear of the bed-plate. They are made of charcoal-iron and are provided with slide-valves of the D type. They are lagged with wood to prevent condensation, and are covered by a heavy metal jacket. The piston is of the usual locomotive type, is cast hollow, and is fitted with spring packing-rings which are of hard cast iron made up of different pieces and so arranged as to prevent leaking; the spring of the ring insures a tight piston. The valve is of the standard D shape, having a good bearing surface on the bottom edge to prevent wear. The piston-rods, valve-rods, and connecting-rods are of steel. The connecting-rods are correctly proportioned in accordance with the cylinder. They have square ends with straps, and are fitted with composition boxes of the best metal.

The cranks are forced onto the shaft by hydraulic pressure and are securely keyed with crank-pins exactly at right angles. The crank-pins are of steel, forced into the cranks by hydraulic pressure and riveted into place. Opposite the crank-pins there is extra metal so as to counterbalance the engine when running at high speed. The winch-heads are of cast iron and designed so as to give the best results as to holding, hoisting, etc. The foot-brakes are of the band type, lined with blocks of wood, which are fastened to the band by means of lag-screws. They are of two forms. In one the band is made in two pieces, and joined by a bolt secured by jam-nuts, by which means the wear is easily and quickly taken up. In the other form the band is in one piece, the adjustment for wear being attained by welding a piece of round iron on one end of the band, cutting a thread in the same,

and passing it through a trunnion on the brake-shaft disk, a jam-nut being used to shorten or lengthen the band as required. In both forms the brake-band is held clear of the drum-flange by means of a lug attached to the fixed band or guard over gear-wheels. The foot-brake is counterbalanced by a movable weight; they are very powerful and very easy to operate, as, once being applied, the action of the load tends to lighten the brake. They will easily hold any load the engines are capable of hoisting. The guard-bands are of wrought iron and are fixed over the gear-wheels in all engines to prevent the rope or any obstruction from getting in the teeth of the gear.

Fig. 134 represents a double-cylinder double friction-drum hoisting-engine without boiler as built by the Lidgerwood Manu-

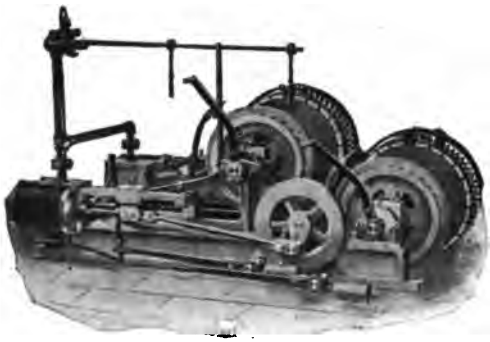


FIG. 134.

facturing Company. It is specially adapted for contractors, bridge-builders, railroad pile-drivers, quarries, and small suspension cableways. It is not a machine to be run at a very high speed, but in places where economy in first cost is a necessity the engine answers excellently, works well, and gives entire satisfaction. They are built of different sizes, as indicated in the following table.

In the last few years electricity has been introduced in many cases as a motive power for mining and public works, and electric engines have been devised both for hauling and hoisting purposes. Fig. 135 illustrates an electric double-drum reversible engine built by the Lidgerwood Manufacturing Company of New York.

Size Number of Engine.	Horse-power Usually Rated.	Dimensions of Cylinders.		Dimensions of Hoisting-drum.		Weight Hoisted Single Rope, Average Speed.	Suitable Weight of Pile-driving Hammer for Quick Work.	Size of Bed-plate.		Estimated Shipping Weight, Lbs.
		Diameter, Inches.	Stroke, Inches.	Diameter, Inches.	Length, Inches.			Width, Inches.	Length, Inches.	
70¾	12	6¼	8	14	16	2,500	2,000	39	76	4.400
71½	20	7	10	14	18	5,000	3,500	44	88	5,525
72½	30	8¼	10	14	20	8,000	6,000	47	88	5,875
73½	40	8½	12	16	24	10,000	8,000	62	107	11,500
74½	50	10	12	16	24	12,000	10,000	62	107	12,000

In general appearance and details it closely resembles the ordinary steam hoisting-engine, with the difference that the cylinders are suppressed. The motive power is applied directly to a shaft by means of cog-wheels engaging those on the motor. This shaft in its turn engages the cog-wheels of the drums, thus causing their rotation.

The motor is of the armored type made by the General Electric Company, and is strong, simple, efficient, and compact. All the movable parts are protected by suitable casings, so that they are not liable to injury from dust or moisture, which renders it especially adapted for hoisting purposes. The gearing from the

Fig. 135.

motor to the intermediate shaft is cut, and is enclosed in an oil-tight gear-case. The drum-gearing is cast very accurately; it is smooth and runs well. It is protected by the ordinary guard-band. The controller is of the railway type, and is mounted so

as to be convenient for the operator. Each controller is provided with a reversing switch, which can be used at will. The friction- and brake-levers are mounted in a rack with notched quadrant and are fitted with thumb-latches. The resistance boxes are of special form and are securely packed on the inside of bed-plate, so that the hoist is self-contained and perfectly portable. These electric hoisting-machines are designed for use with a direct current of 500 or 250 volts. The following table gives the sizes of the motor as built by the Lidgerwood Manufacturing Company, and these various sizes apply to either voltage.

Number of Hoist.	Motor Horse-power.	Style of Motor.	Size of Drums.		Hoisting Duty.		Revolutions of Motor, 500 Volts.	Estimated Shipping Weight, Lbs.
			Diameter, Inches.	Face, Inches.	Weight Hoisted, Lbs.	Speed in Feet per Minute.		
516	10	L. W. P. 5	12	16	2000	150	650	4,150
517	15	G. E. 800	14	20	2500	175	460	6,700
518	25	G. E. 800	14	22	3500	175	575	7,100
519	35	G. E. 1000	16	24	5000	200	500	9,200
520	50	G. E. 1200	16	28	7000	200	550	12,825

The various motive powers used in connection with the work of excavation are steam, compressed air, and electricity. As a rule steam is generally used for hauling, hoisting, and excavating purposes; compressed air is employed for driving the machines in the excavation of rock and in hoisting; while electricity may be used for all of these purposes.

In opening trenches for the construction of roads, when rock is encountered it is generally excavated by blasting and the holes for the charge are bored by machines. A battery of three or four drills is set up to do the work and a derrick erected for loading the stones into the cars or wagons, and is operated by a double-drum reversible engine. The steam both to the drills and the engine is supplied by a boiler of about 60 H.P. located near by. This will send the steam to the work through an iron pipe line with T joints, where connections are made for the drills.

When the work is so large that more than one battery of drills

is employed, the several batteries will be widely separated. In such a case the steam can be supplied in two different ways: either by numerous boilers, each one of them located near a working-point, or else by a single boiler of large capacity. In the former case it will be necessary to employ as many different boilers along the work as there are points of attack. This will involve heavy expenses on account of the extensive plant, the number of attendants that the boilers require, the great number of water-carriers employed, etc. In the latter case it will necessitate a boiler plant of very large capacity and a steam-pipe line of great length. It is well known that steam in long pipes condenses, and consequently there will be a large amount of waste. It will then be more economical to employ some more convenient motive power.

For the reason that compressed air can be transmitted even miles without any sensible loss of pressure it can be conveniently used in the excavations of great magnitude and greatly extending in length. The plant will be located at some point that will be convenient for handling the coal and water. The plant consists of a certain number of boilers which provide steam to drive the compressors. The air compressed is stored in one or more receivers, from which through the pipes it is distributed to the various working-points along the line. The number and capacity of the boilers as well as that of the compressors, the dimension of the receivers and the diameter of the various pipes along the line of work, should be in proportion to the expected work and must be fixed by the engineer.

Still another motive power to be used in works of excavation is electricity. Since it may be employed for different purposes, as, for instance, in driving the drills for boring the holes for the charge in the excavation of rocks, in driving the engines for hoisting materials, and for hauling the trains loaded with the excavated earths, it has certainly great advantages over any other motive power. Besides it can be produced and transmitted at a smaller expense than the other powers, and this is the reason why so many engineers consider electricity as "the power" for

any work. There is no doubt that it is the most convenient motive power for hauling cars, and this has been clearly demonstrated on the enormous development of electric roads built and under construction all through the world, even in places where steam roads would have been a great failure. But although electricity is extensively used for mining purposes, it has not been adopted yet on public works, and this is perhaps due more to prejudice than to any real good reason.

The writer knows many experiments which have been recently made tending to demonstrate that electricity is the most economic motive power to be used in works. Although this was true in the particular cases considered it cannot be deduced that such a statement applies to every case. The particular conditions of the work at hand as well as those depending upon the locality in which the excavation is made should be taken into consideration. Electricity is transmitted by means of wires supported by simple posts which can be erected at a great distance from one another, and its transmission is very economical when compared with the cost of laying down an iron pipe line for compressed air. But electricity when transmitted to a distance is dispersed on account of the resistances encountered, and only a part of that produced will be available for work. In using electricity it is necessary to take into consideration the danger which arises from the presence of live wires, especially when working in narrow spaces, as in the trenches, and the accidents that may befall the workmen. For these reasons, notwithstanding electricity is more economic, compressed air will be found in the end the most convenient.

In regard to the comparison of the various motive powers to be used in the work, the *Engineering News*, in describing Section 3 of the New York subway, says:

Before compressed air was adopted as a motive power for the subway work the contractor made a careful study as to the availability of steam and electricity. Although steam appeared the most economical it necessitated many isolated boilers and engines, with endless dirt and confusion, besides the disadvantage

of working many union engineers. Electricity appeared economical, but there was no assurance of satisfaction in electric drills. An electric-power plant would have proved an expensive installation, and the cost of electric power from local companies was about double the estimated cost of compressed air.

The adoption of compressed air on this section was quickly followed by the installation of similar plants for other sections of the subway, and it has proved even more satisfactory and economical than was anticipated.

CHAPTER XIX.

ANIMAL AND MECHANICAL LABOR.

ALL excavation is done by men working in gangs. Each gang is in charge of a foreman, and they are all under the direction of a superintendent. The unit of work is the day's work, which is usually ten hours for all but mechanics, who work an eight-hour day. When the work is carried on continuously, one set of men succeeding another at intervals of six, eight, or ten hours, the men are said to work in shifts. The number of men composing a gang should be that which will accomplish the most work in a given time under the prevailing conditions.

Superintendent. — Honesty, activity, and intelligence combined with a large amount of practical experience on public works are the requirements of a good superintendent. He must supervise the work and direct the various gangs, so that it is accomplished according to the engineer's plans, which he must be able to read accurately. He must know how to stake out work; how to arrange so that the various gangs will have steady work; how to detect materials that are not according to specifications, and how to measure the work and check the measurements of the engineer. He must have the intelligence and practical experience which will enable him to detect error or imposition on the part of the engineer, and to oppose orders which are against the interests of his employer. He must also be versatile in solving difficulties which occur unexpectedly in the work.

Foremen.—Any workman so well acquainted with the problems and intricacies of his trade that he is not only able to do the work himself but to direct other men intelligently can be em-

ployed as a foreman. Foremen should not be appointed through "pull," as is usually the case in nearly all public work in this country, but they should be selected from among the best, most intelligent, honest, and active workmen. The duties of the foreman are to carry out the orders of the engineer or superintendent, and to dispose of the workmen in such a manner as to obtain from them the most efficient work. He must be considerate with his men; scolding and even discharging them when they are lazy, but not insulting nor continually yelling at them, or else he will obtain the opposite effect to the one he desires. The foreman must watch out for defective materials, and lay them aside for the engineer or superintendent to examine. If he can keep records of the work and time he will increase his value by saving the services of a timekeeper. The principal duty of the foreman is to look after the interests of his employer, and to this end he must closely watch his men to see that none is ever without work, and that time is not lost in shifting from one task to another. He must warn the men of danger, and watch out against the danger of accident. In rock excavation he must be perfectly acquainted with drilling-machines, and have a thorough knowledge of blasting. He must locate the position of the holes to be drilled, and fix their depth after these have been determined in a general way by the engineer. He must take personal charge of dynamite and other explosives; he must make the preparations for blasts, and, generally, he will take charge of the firing operations, establishing the danger-lines and seeing that all persons and machinery are out of danger from injury by the blast.

Classification and Capacity of Workmen.—Excavation is performed either by manual labor or by machines, consequently the men employed in any work can be grouped into mechanics and laborers. Mechanics are, as a rule, intelligent and educated men, having a good knowledge of the principles of mechanics and wide experience and skill in their trade. As engine-drivers have to possess a State certificate which is obtained only after passing an examination, they may be assumed to be always well acquainted with their trade. Membership in the labor unions is also a guar-

antee that a mechanic is competent to do the work for which he is employed.

Of late years, because of the extensive and increasing use of drilling-machines in rock excavation, and the simplicity of these machines, which do not necessitate special mechanical skill in their handling, contractors have taken to operating them by intelligent laborers. These get better wages than ordinary laborers, but smaller wages than mechanics, and form a middle class between the two. The duty of the drillers is to regulate the lowering of the machine, change the bits, and remove the drills from one place to another according to the orders of the foremen. Drillers must take great care of the machine entrusted to them, and must be active, steady, and patient in their work, since the success of the drilling depends upon them. They must thoroughly understand the drilling-machine and its work, and be able to change the defective parts for the new ones.

All works of excavation, whether of rock or earth, when not done by machine are done exclusively by ordinary laborers. In this country contractors and engineers do not pay great attention to the work of their laborers, who receive the same wages, varying from $1 to $1.50 per day. The writer thinks this a great mistake, since there are many laborers not worth half of what they get, while there are others that deserve more than twice what they usually get. Standard wages are possible with mechanics, especially when from a union, because the simple fact of membership in the union is a proof of their ability, and so when a contractor engages one of these men, he knows what his ability is, and consequently what he may expect from him. But when a contractor engages a shoveler for instance, at the prevailing wages, he does not know what kind of workman he is, and what he is able to do. The shoveler may be a strong man and one with experience, or he may turn out to be a man who never did any similar work before, but took the shovel as the last resort against starvation.

As a rule the cheapest work is obtained from men getting the highest wages. The author knows of an experiment made by

the Italian Engineering Corps in Rome, in which the work of the different laborers was accurately tested. The laborers were divided into three gangs, according to the locality they came from and the wages they were used to getting, these being 40 cents, 50 cents, and $1, respectively. The work was ordered to go on as usual without the laborers knowing that the efficiency of their work was to be tested. After a couple of weeks the work of the different gangs was measured, and it was found that the workmen paid at $1 per day did more than twice the work done by those paid at 50 cents and nearly three times that done by the laborers at 40 cents. It was also ascertained in this case that highest-priced labor was the cheapest in the end.

The diet of the laborers has a great influence upon the efficiency of their work; a properly fed man gives, as a rule, a greater amount of work than a poorly fed one. This fact is of special importance to contractors where on account of the location of the work they must either directly or by contract furnish provisions to their men. It is to their interest to see that the men are properly fed. Sometimes the contractors sell their men poor foods, or when good it is sold at very high prices. In both cases the losers are the contractors. In the example referred to above, in investigating the diet of the various gangs of laborers it was found that the men who did the greater amount of work were well fed, having two meals a day, their diet consisting of fresh meat and bread and wine. Those paid at 50 cents got two meals a day, one consisting simply of bread and cheese and the second of corn-meal and vegetables and salt meat or fish, with a little wine or none at all. The diet of the laborers at 40 cents per day was even poorer.

Laborers must be steady in their work; a slow but continuous speed of work is far more efficient than one began at a high rate and slowing down continuously all through the day. A man cannot work continuously, but needs rest, and the best way is to alternate the periods of his work with the moments of rest. The more regularly these are alternated the greater will be the endurance of the man and consequently the more efficient will be his

work. An intelligent contractor should prevent the yelling and "hurry-up" orders given continuously by ignorant foremen. By this procedure they intend to show their attachment to the work and in their ignorance honestly believe that they are looking after the interest of the contractor, while they are obtaining just the opposite result. These foremen should be immediately discharged. There are still contractors, however, though happily very few, who believe that the only way of obtaining efficient work from the men is by yelling and scolding. Mr. George H. Parker, a civil engineer in charge of the works at Keney Park, Hartford, Conn., states that while the work of handling 10 or 12 cu. yds. of earth is considered a fair day's work, he has obtained a work of loading 20 or more cu. yds. per day with the same effort. He found that the actual time for handling the sand per shovel was from fifteen to twenty-five seconds, and then he ordered each man to work twenty-five seconds and rest twenty-five seconds alternately through the day. To this quick work and then an absolute and unquestioned right to rest for an equal time he ascribes the success of his system. Mr. Parker also found that his men worked the quickest in the morning, slower in the afternoon, and still slower at night. In like manner Monday was the laborer's best day and Saturday his worst day as a rule, though weather conditions modify this.

Apart from any humanitarian or philanthropic idea, laborers are considered by engineers and contractors simply as living working-machines; they are hired and paid for their work, and consequently it is necessary to know the amount of work to be expected from them.

In the English-speaking world work is measured by the foot-pound, which is the effort required to raise 1 lb. in weight to 1 ft. in height. In Europe and everywhere else where the metric system has been adopted, the unit of measure of work is the kilogrammeter, or the effort required to raise the weight of 1 kilogram to the height of 1 meter. A kilogrammeter is equal to 7.21 ft.-lbs. A man can exert in a day only a certain amount of effort and no more; thus his daily work can be valued by the foot-pounds

he can lift in a day. This number has been variously estimated by different authors. Rankine says that the daily effort exerted by the muscular strength of a man is the product of three quantities—the useful resistance, the velocity with which that resistance is overcome, and the number of units of time per day during which work is continued. For each individual man there is a certain set of values of these three quantities which makes their product a maximum, and it is therefore the best for economy of power; and any departure from that set of values diminishes the daily effect.

The following table of the effects of the strength of men employed in various ways was compiled by Rankine from the works of Poncelet, General Morin, and others.

		R, Lbs.	*V*, Feet per Second.	*T*, 3600 Hours per Day.	*RV*, Ft.-lbs.	*RVT*, Ft.-lbs. per Day.
1	Raising his own weight up stairs or ladders	143	0.5	8	72.5	2,088,000
2	Raising his own weight up stairs or ladders	143	0.5	10	72.5	2,616,000
3	Hauling up weight with rope	40	0.75	6	30	648,000
4	Lifting weights by hand	44	0.55	6	24.2	522,720
5	Carrying weights up stairs	143	0.13	6	18.5	399,600
6	Shoveling up earth to a height of 5 ft. 3 ins.	6	1.3	10	7.8	280,800
7	Wheeling earth in barrows up slope 1 in 12 with horizontal velocity 9 ft. per sec. (returning empty)	132	0.075	10	9.9	356,400
8	Pushing or pulling horizontally	26.5	2.00	8	53	1,526,400
9	Turning a crank or winch	18	2.5	8	45	1,296,000
10	Working pump	13.2	2.5	10	33	1,188,000
11	Hammering	15	?	8?	?	480,000

Colombo in his "Engineers' Handbook" gives the following data: "The average work per second, working all day long, can be assumed between 6 and 9 kilogrammeters, being equal to one-twelfth or one-eighth of a horse-power. Working alternately with periods of rest his effort can be considered as varying between 18 and 24 kilogrammeters. Working continuously on a crank with a velocity of .75 or .9 meter per second his effort can be assumed as between 8 and 10 kilogrammeters, while working for a short time only

followed by long stretches of rest he may exert efforts equal to 25 or 30 kilogrammeters per second.

"The maximum efforts that a man can exert in pulling or pushing for a short time only is between 50 and 60 kilogrammeters. He can lift a weight of 200 or 300 kgms., and carry on his shoulders a weight of 150 or 200 kgms. A man can walk with a velocity of 1.25–1.40 meters per second; in walking fast he can cover a distance varying from 1.50 to 1.70 meters per second, and he can run from 2.20 to 7 meters per second."

The muscular strength of animals is utilized in different ways in public works; the principal ones being in carrying materials on their backs, as in mountain regions, or in pulling them in carts and wagons. The animals generally used are mules and horses. Mules are tougher and will endure more hard work than horses; the former are very useful in mountain work, but horses are more commonly employed for hauling carts and wagons.

Mules, when transporting materials on their back, can easily carry weights varying from 200 to 400 lbs., and travel long distances; for short trips they will usually carry from 360 to 500 lbs. on horizontal roads. They move with a velocity which can be assumed at 3 miles per hour on ordinary roads, but going up incline they do not travel more than 2¼ miles per hour. The total distance traveled in a day can be considered at 20 miles.

Horses hitched to the carts and wagons, according to the condition of the road, may carry loads varying from 1200 to 2500 lbs. besides the weight of the vehicle. The average weight of a cart can be assumed at 1300 lbs., and since in doubling the number of horses there it is not necessary to increase the weight of the cart, the greater will be the quantity of the hauled materials, and this is the reason why, in order to better utilize the strength of animals, they are worked in teams, and why cars are constructed for two, three, and four horses. Two horses can easily haul 3000 lbs., three horses 4500 lbs., and four horses 6200 lbs. Besides it is more convenient to have the horses work in teams than alone, on account of the wages of the driver. On carts hauled by only one horse, which has also to drag the total weight of the cart, the

wages of the driver must be paid entirely by the small quantity of material hauled; while, if working in teams, the total work of the second horse will be utilized exclusively for hauling material, and only half the wage of the driver must be paid by the work of each horse.

The following table, given by Gasparin, clearly indicates the efficiency of the work of horses working alone and in teams:

	Useful Load.	Load per Horse.	Weight of Vehicle.	Total.	Average Load per Horse.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Cart, 1 horse.......	2070	2070	1100	3,170	3170
Wagon, 2 horses ...	4349	2173	1980	6,329	3164
" 3 " ...	6012	2004	2640	8,652	2884
" 4 " ...	8140	2035	2970	11,110	2777
" 5 " ...	8635	1727	3300	11,935	2387
" 6 " ...	8672	1445	3300	11,972	1978
" 7 " ...	8751	1249	3300	12,051	1721
" 8 " ...	7444	1012	3300	10,744	1343

From this it is seen that it is economy to increase the number of the horses up to a certain limit, which is four. Beyond this number the efficiency of the work of each horse greatly decreases.

In this book, for calculating the cost of hauling materials when animals were employed as motive power, the price of hiring teams was usually taken into consideration. But if a more accurate analysis should be required, the cost could be easily found by considering the following items: Interest on the capital invested in acquiring the horses, daily cost of maintenance, including the food, stable, stableman, insurance, medicine, shoes, etc., and sinking fund. The total amount divided by the number of working days in a year will give the correct cost of the daily work of a horse.

The work of horses has been variously estimated by different authors. Rankine deduces the efficiency of their work by taking into consideration the same three elements he employs for calculating the muscular strength of men, viz., the resistance, the velocity, and the time, and he considers the work on the product of these three quantities:

	R.	V, Feet per Second.	T.	RV.	RVT.
Cantering and trotting, drawing light railway carriage...	Min. 22½ Mean 30½ Max. 60½	14⅔	4	447½	6,444,000
Horse drawing cart...........	120	3.6	8	432	12,441,600

Colombo in his handbook for engineers gives the following data: "A horse working all day can drag a weight varying between 40 and 60 kgms. per second, corresponding to 40 or 50 kilogrammeters, equivalent to ½ or ⅔ of a horse-power. For a short time he can drag a weight of 250 to 400 kgms. per second. The speed of the horse in running is 14 meters per second, galloping 10 meters, trotting from 4.4 to 3.3, walking fast about 2 meters, and in ordinary walking from 0.90 to 1 meter. On good horizontal roads a horse may drag besides the vehicle a load of 350 to 500 kgms. when trotting, and between 1000 and 1500 kgms. when walking."

A whole book could be written concerning the manner of working the various machines already described. The general characteristics of several of the principal mechanical appliances used in the excavation of earth and rock, as well as for transportation purposes, have been given in the preceding chapters; a little space will be devoted here to the machines as considered from a general point of view.

In the selection of any machine it is the duty of the engineer to carefully examine the various conditions of the work, and to decide which of the various machines will be the most efficient in the particular case he has to deal with. To facilitate such a selection, in the description of the various kinds of machines reviewed in the preceding chapters, it has been indicated in what circumstance the work of each machine will be the most efficient. Once the engineer has selected the type of machine most convenient for his case, he should get the catalogues of the various manufactures, thus providing himself with a full description of the different machines of the same type that are found on the

market. Since all these machines, as a rule, are very similar in their principal parts, although they greatly differ in the details, and since every manufacturer will represent his machine as the best and most efficient of all, it will be desirable for the engineer to obtain from the manufacturers a list of places where their machines are at work. By visiting these places the engineer can personally ascertain from the men in charge of the machines their advantages and defects. Keeping record of the efficiency of the work of every machine, and the statement of the various engineers in charge of the machines, it will be very easy to select the best machine by a simple comparison.

As a rule the most desirable machines are those solidly built and provided with the smallest possible number of parts all interchangeable, and those which will perform the work at the lowest figure. The price should not have influence on the selection of a machine, because in many instances a very expensive machine is not always the best, and a very cheap machine is usually found in the end to be the most expensive.

Together with the description of the various machines, there has been given also the cost of the unit of volume of the work performed. This, however, cannot be taken as the real cost, because it was based exclusively on the working expenses of the machine. There are other general items to be considered which tend greatly to alter the cost of the unit of volume of the work. These are the interest on the capital invested in the machine, the probability of continuous work, the necessary repairing required to keep the machine in good working order, and, finally, the sinking-fund.

The interest of the capital invested in the contractor's plant is a negligible quantity when the plant consists only of hand-tools, but it assumes great importance when it contains several large machines. If the capital invested in purchasing machines had been invested in any other commercial investment, it would have certainly given in return an interest of 5 or 6 per cent. per annum. By purchasing the machine the contractor does not get any more this return from his money, and he must obtain

it from the work of the machine. Consequently, before calculating the net profits of any operation, amongst the yearly expenses of any machine should be considered first the interest of the invested capital at the commercial ratio.

In buying a machine it is necessary to consider also the probability that the contractor has of getting continuous work. In fact, if a machine is bought for a single work, notwithstanding its running expenses are so low as to perform the work at a small cost, this is not really the case because of the other expenses to be charged to this work alone, and which tend to greatly increase the cost of the unit of volume of the work. There is no doubt that machines tend to lessen the cost of work, but to do so they must work as continuously as possible. Suppose that the yearly expenses of a machine, including interest, sinking-fund, etc., will amount to $700; if the machine is working 200 days per year it will be necessary to add $2.50 to its daily expenses; while if it works only 50 days in a year the daily expenses must be increased by $14. Considering the capacity of the machine at 500 cu. yds. per day in the former case the cost of the work would be increased by only ½ cent per cu. yd.; while in the second case the cost would be increased by nearly 3 cents per cu. yd.

Another important item to be considered in machines is the wearing and repairing. Machines, no matter how strong they are built, will undergo wear, especially on the parts which are most subjected to sudden strains. To keep these machines in good working order it is necessary to repair them continuously. It will then be necessary to spend every year a certain amount of money in order to keep the machine in good condition. Such an amount varies with the machine, the quality of the soil handled, and other circumstances. The sum which is usually laid aside every year for repairing varies between one-third and one-fifth of the total cost of the machine, and such a sum should be subtracted from the profits of the operation to obtain the net profit.

Another important item in connection with the calculation of the cost of the unit of volume of the work performed by the machine is the sinking-fund. Any machine, notwithstanding

it is kept in good order, will last only for a certain number of years, and then the repairing that will be required to keep the machine in working order will be so great that it will be more economical to buy a new machine than to renew all the various parts of the old one. The money for the acquisition of a new machine should be obtained from the work of the former machine. In fact, if a contractor pockets every year the profits got from the work, without laying aside an amount of money which, with its accumulated interests, after so many years will give the original amount of the cost of the machine with which to buy a new one when the old is gone, he will also, together with the so-called dividends, pocket part of the capital. The sinking-fund is that sum which it is necessary to lay aside every year, so that after a given number of years these sums, together with their accumulated interest, will give the required amount required to buy a new machine.

The writer has often noticed that the sinking-fund is an item easily forgotten in this country. A few years ago one of the great railroad systems of the country, whose shares were quoted above par on account of the big dividend paid for some years in succession, all at once went into the hands of the receiver, and the value of the shares fell near to nothing. The reason of such a sudden change was that the old administration never thought of the sinking-fund, which was, instead, distributed to the shareholders as dividends. The consequence was that the rolling-stock was old and needed to be renewed, and as no money for such a purpose had been laid aside in the previous years, in order to provide it, it was found necessary to reorganize the company and borrow money. Now, if even the big railroad corporations sometimes overlook such an important item, it may easily be forgotten by contractors.

Expensive machines, notwithstanding they are continuously repaired, will not last longer than twenty years, and consequently it is necessary to lay aside every year a certain sum which, together with its compound interest at the end of twenty years, will give the original cost of the machine, so as to have at hand the sum to

buy a new machine, thus perpetuating the capital; otherwise, part of its capital will have been destroyed. The age of a machine varies between ten and twenty years; tools last only a few months.

The sum which it is necessary to lay aside every year is calculated by means of the formula

$$a=S\frac{r}{(1+r)^n-1},$$

in which r is the annual interest of a dollar, S the total amount of the sum required after so many years, and n the number of years. The various values of $\frac{r}{(1+r)^n-1}$ for the different years and rate of interest are given in the following table:

Number of Years.	$n=4$ Per Cent.	$n=5$ Per Cent.	$n=6$ Per Cent.
1	1.000	1.000	1.000
2	0.4902	0.4878	0.4854
3	0.3203	0.3172	0.3141
4	0.2355	0.2320	0.2286
5	0.1846	0.1810	0.1774
6	0.1508	0.1470	0.1434
7	0.1266	0.1228	0.1191
8	0.1085	0.1047	0.1010
9	0.0945	0.0909	0.0870
10	0.0833	0.795	0.0759
12	0.0665	0.0628	0.0593
15	0.0499	0.0463	0.0430
20	0.0336	0.0302	0.0272
25	0.0240	0.0209	0.0182

CHAPTER XX.

THE DIRECTION OF EXCAVATION WORK.

It is not an easy matter to correctly direct a work of excavation, and as a rule the most successful contractor is he who handles the materials in the most economical way. No general rules can be given for organizing a work of excavation, every one presenting some characteristic differences which only the keenest observation can detect, and from them suggest means to overcome the difficulties in the simplest and easiest manner. To give, however, an idea of how the work should be directed, several cases will be considered here, which vary with the extent and magnitude of the work, and also with the manner of excavating and the means of transportation adopted. For the sake of classification a few cases will be reviewed here in the following order:

Earthworks: Earth.

- **Cut of small depth extending over a large area.**
  - **Cut done by plows.**
    - **Transportation by scrapers.**
  - **Cut done by New Era grader.**
    - **Transportation by carts and wagons.**
- **Cut deep and long and narrow.**
  - **Cut done by hand.**
    - **Transportation by wheelbarrows.**
    - **Transportation by carts and wagons.**
    - **Transportation by industrial railways.**
  - Cut done by machine.
    - Down-digger.
      - Cars hauled by locomotive.
    - Up-digger.
      - Cars hauled by locomotive.

The excavation of earth extending over a large area of small depth can be conveniently performed by means of a plow

and the materials removed by scrapers, which can be either of the drag or wheel types. The average work of a plow in heavy soil can be assumed at 250 cu. yds., while in light soil it can remove on an average 500 cu. yds. In directing the work executed by means of scrapers it is of great importance to know (1) the number of scrapers to be employed per each plow; and (2) the manner in which the work should be arranged.

In regard to the number of scrapers to be employed, this varies with the quality and capacity of the scrapers and the distance to which the materials must be hauled. Drag-scrapers are very convenient for short hauls. It has been seen that they may haul from 74 to 11 cu. yds. per day, according to the distance, varying from 100 to 600 ft. In heavy soil a single plow will give work to 3.5 drag-scrapers hauling the materials to 100 ft. distance; it will require 7 drag-scrapers to haul the same quantity of material to 200 ft., and 2 drag-scrapers should be added for each 100 ft. in length over 200 ft. distance. When the material is very loose, so that the average quantity of earth removed by the plow in a day is about 500 cu. yds., each plow will give work to a number of drag-scrapers double that indicated above for the heavy soils, and consequently for distances greater than 200 ft. one scraper should be added for each 25 ft. in length of the haul.

Wheeled scrapers are far more economical for long hauls than drag-scrapers. They are of different capacity, varying from 9 to 14 cu. ft., and since the work of the plow will remain the same, the number of the wheeled scrapers required to remove the earth loosened by the plow will be smaller. This number, however, will vary with the capacity of the scraper. Thus 3.5 wheeled scrapers of 9 ft. capacity will be required to haul to 200 ft. distance the earth removed by a plow in a day's work; 5.5 to 300 ft.; 7.5 for 400 ft. distance, and, in general, 2 scrapers more for every 100 ft. in additional length. A larger number of wheeled scrapers will be required for removing the earth where it is sandy and light, and as a rule in such a case a number of scrapers double the one required for heavy soil will be required. When wheeled scrapers of large capacity are employed the number of scrapers

will be 2.5 for 200 ft. distance, 3.5 for 300 ft., 5 for 400 ft., and 1 more scraper for every 100 ft. increased distance of haul, and double this number for sandy and light soils.

In regard to the manner of arranging the work, it is necessary to observe that the scrapers should travel continuously, and consequently they must travel in circles or at least along two parallel roads with a loop at each end. Scrapers in earthwork excavations can be employed in building up embankments from cuts or borrow-pits, in leveling the ground for reservoirs or large railroad yards or sites for factories, or in the transportation of earth from the point of excavation to the point of loading into more powerful and economical vehicles.

Fig. 136 clearly indicates the manner of building embankments for new roads, when the earth is taken from along the sides

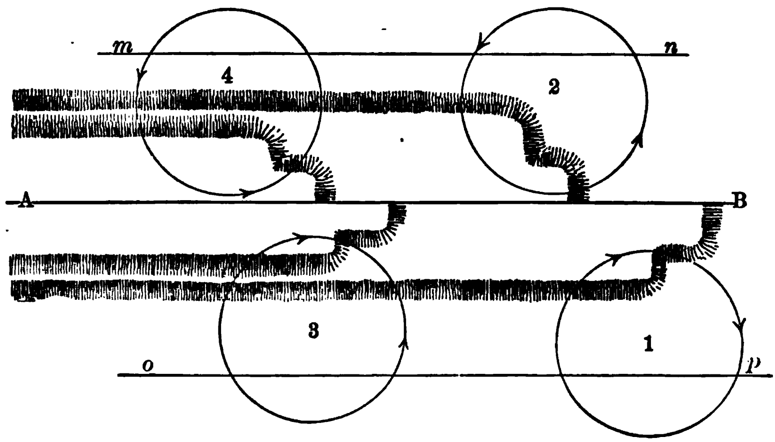


FIG. 136.

of the road. The embankment is built up in layers 18 ins. deep each, and they succeed each other in such a way as not to interfere with one another. The work proceeds on both sides of the axis of construction at the same time, and follows the order indicated in the figure. At first a battery composed of several scrapers works in section 1, building up half of the embankment, with the slope reaching the lateral terminal of the projected road; 10 ft. or

more away another gang works on the other side of the axis of the construction, as indicated at 2 in the figure. A third gang then follows at 3, at a distance not less than 10 ft. away from 2 and 20 ft. from 1, and builds another layer above the one that has been previously placed. The following gang, 4, builds the other portion of the embankment on the other side of the axis of construction. In this manner the embankment is built for a height of 36 ins.; but if it is required to be still higher, other gangs can be employed in succession to those mentioned.

The earth is taken from along the lines *m*, *n*, and *op* at the left and right of the embankment to be constructed, and the trenches can be used as drains for the road. The earth can be removed by one plow or more, according to the length of the haul, and, consequently, to the number of scrapers to be used. The scrapers travel in the direction indicated by the arrows. A similar but opposite arrangement can be used in excavating a trench in which the materials are to be deposited on each side of the cut, as, for instance, in the construction of canals for drainage or irrigation purposes.

Scrapers can be used also for removing materials in leveling up the ground for the construction of storage-reservoirs or railroad yards. In these cases the work is directed in various ways, depending upon the conditions of the locality. The land to be leveled may contain many isolated knolls which have to be cut down and the materials used for filling; or it may be on a side hill, and all the materials from the cut employed in the fill. In the former case the work may be arranged in the way indicated in Fig. 137. At each one of the knolls a plow may loosen the earth and give work to scrapers, which will travel radially, dumping the earth all around where the filling is required. The diagram given in Fig. 137 shows an ideal solution of the case, but it gives a fair idea of the work of scrapers where the material from knolls must be deposited all around. The arrows along the edge of the knoll represent the course of the plow.

In the construction of large yards, in side-hill work the earth can be removed in the manner indicated in Fig. 138. The plow,

trenching back and forth along the edge of the cut, removes the earth, which is taken up by the scrapers and dumped where the filling is required. The number of plows to be employed depends upon that of the scrapers that have to be served, and the number

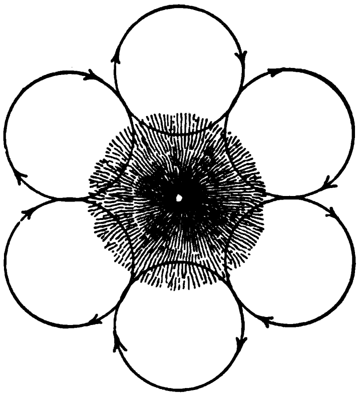


FIG. 137.

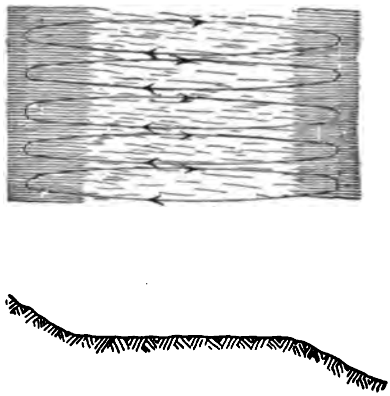


FIG. 138.

of scrapers, as has been remarked above, depends upon their capacity and the distance of the haul.

Scrapers can be conveniently employed in transferring materials from the point of excavation to a place where the earth is dumped into larger and more efficient vehicles for distant hauling. In such a case a narrow trench is cut in the ground by means of plow and scraper. The trench is then widened so as to allow a wagon to easily pass through; and it is carried down to such a depth that when a platform is placed across the trench and flush with the ground-surface, it will not interfere with the wagons. The trench, as indicated in the longitudinal section of Fig. 139,

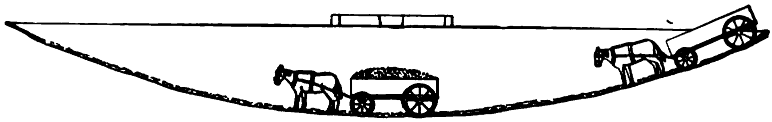


FIG. 139.

is excavated with a double inclination converging toward the center; one of the inclines is steeper for the descending wagons,

while one comes to the surface at a smaller inclination to facilitate the ascent of loaded wagons. Between the edges of the trench and just above the deep portions is placed a platform flush with the ground. This is composed of square beams placed across the trench, having on top heavy planks running parallel with the trench itself. In the center of the platform there is a hole 3×3 ft. The scrapers, taking up material around the trench, pass over the platform, and when the slot is reached the driver dumps them. A wagon standing under the slot receives the earth, and when filled, moves to give place to another. Fig. 140 represents the

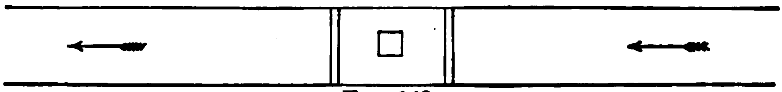


FIG. 140.

plan of the trench, and indicates the course of the scrapers as well as that of the wagons.

The New Era grader is very convenient for the construction of railroads where the ground is level, so that only a small embankment is required, formed with materials excavated from trenches on each side of the road, which are to be used as drains. It is very convenient also in the excavation of irrigating canals, where the earth is to be deposited along the edges of the canal to form the levees; also in the construction of large reservoirs, and in leveling the ground for large railroad yards, etc. The manner of doing the work in these various cases will be briefly reviewed.

In the construction of small embankments for single- or double-track railroads, the machine runs over the trench to be excavated at the left-hand side of the road. In advancing the machine, the earth removed going up the incline (whose length will depend upon the distance from the trench to the center of the road) will be dumped so as to form the embankment. After having traveled to some distance on one side, the machine returns to the starting-point by following the line of the trench on the opposite side of the road, and dumping the material so as to form the right side of the embankment. By passing several times along the same route, always proceeding a

little inward or outward, the embankment will be completed without the necessity of employing any vehicle for the transportation of the materials.

It will take twelve days to construct embankments 16 ft. wide and 3 ft. high, for a single-track railroad, or 28 ft. wide and 2 ft. high for a double-track road, according to the diagrams given in Fig. 141. Assuming the daily cost of working of the New Era

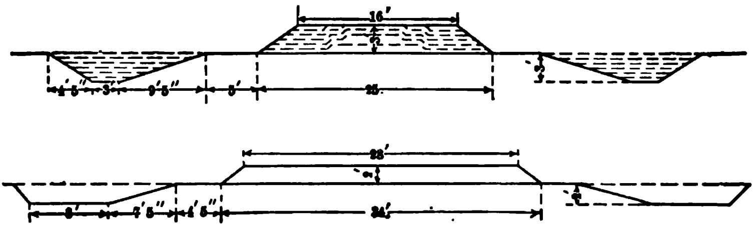


FIG. 141.

grader as $18, as given by the manufacturers, it will cost $216 to build embankments for one mile of road of the dimensions indicated above.

New Era graders are very efficient in the excavation of ditches and canals for irrigation purposes. The diagram (Fig. 142) in-

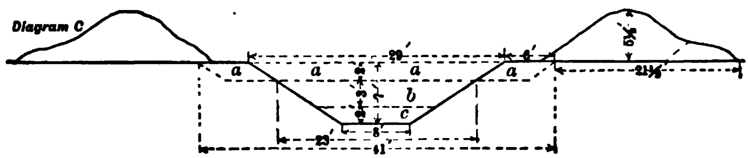


FIG. 142.

dicates the manner of excavating a ditch 29 ft. wide on top, 8 ft. wide at the bottom, and 7 ft. deep, as given by the Western Wheeled Scraper Company. The banks have slopes of 1½ to 1, with a 6-ft. berm on each side, and the embankments formed with the excavated materials are 21½ ft. wide and 5½ ft. high. It will require the handling of about 25,500 cu. yds. per mile, and it will take about 25 days to finish each mile. As this is a deeper ditch than can be cut directly with this kind of machine, it is necessary at first to take out the section marked *a* in the figure, 41 ft. wide and 2 ft.

deep, using a 21-ft. elevator, working each plowing from the outside to the center, and delivering the earth on each bank. Then narrow the work down to 23 ft., as shown by section *b*, and take out 3 ft. with slopes of 1½ to 1, working from the outside to the center, and delivering the earth on each bank as before. Then the remaining 2-ft. section *c* is taken out by cross-firing, working from center to outside, and delivering the earth on the opposite shoulder, which was prepared by taking out the first 2 ft. The manner of handling the work, by excavating the earth from the left side of the ditch and dumping it on the right bank, and vice versa, is called cross-firing.

The real cost per mile for excavating a ditch of the dimensions given will be $450. This, however, does not include the general expenses, superintendence, contractors' profit, etc. Fig.

FIG. 143.

143 gives a fair idea of the excavation of trenches by means of the New Era grader.

In ditches of larger dimensions, or when the earth from the

cuts must be used for fills, the hauling is done by means of dumping-wagons. The work should be arranged so as to have always an empty wagon at hand ready to be filled. As soon as one wagon is loaded an empty one must take its place under the incline. The success of the work consists in having the proper number of wagons serving the machine, and this number should be in proportion to the distance of haul. To load 1000 cu. yds. in ten hours a wagon must be at the side of the machine every 30 to 50 seconds. A team with a dumping-wagon will haul to a distance of 90 ft., dump, and return in one minute. When the haul is not over 50 ft., four wagons will attend the machine. For each additional 90 ft. another team must be added.

Fig. 144 represents the Western elevating-grader, ditcher,

FIG. 144.

and wagon-loader, a machine similar to the New Era grader, excavating and loading earth into wagons. It shows a wagon being loaded while both machine and wagon are in motion.

The following table, indicating the number of wagons to be used, the total daily cost of handling the earth, including the cost of operating the machine and the wagons necessary for the transportation of the earth, as well as the cost per cubic yard of earth removed, is given by the F. C. Austin Manufacturing Company, the manufacturers of the New Era grader. These estimates

are based upon the cost of handling on the level, but for deep excavations in large canals or high embankments, in constructing levees or reservoirs, 10 per cent. should be added to the price given. For cutting down hills where wagons load heavily for down-hill haul, 10 per cent. can be deducted from the price named. The wage-rate assumed is $3.50 for man and team.

Length of Haul, Feet.	Number of Wagons.	Total Daily Cost.	Cost per Cubic Yard, Cents.
140 to 320	5	$34.75	$3\frac{1}{2}$
410	6	38.25	$3\frac{7}{8}$
500	7	41.75	$4\frac{1}{8}$
590	8	45.25	$4\frac{1}{2}$
680	9	48.75	$4\frac{7}{8}$
950	12	60.25	6
1220	15	70.75	7
1670	20	88.25	9
1940	23	98.75	10
2300	27	112.75	$11\frac{1}{4}$
2600	30	122.25	$12\frac{1}{4}$
3000	35	157.25	$15\frac{1}{10}$

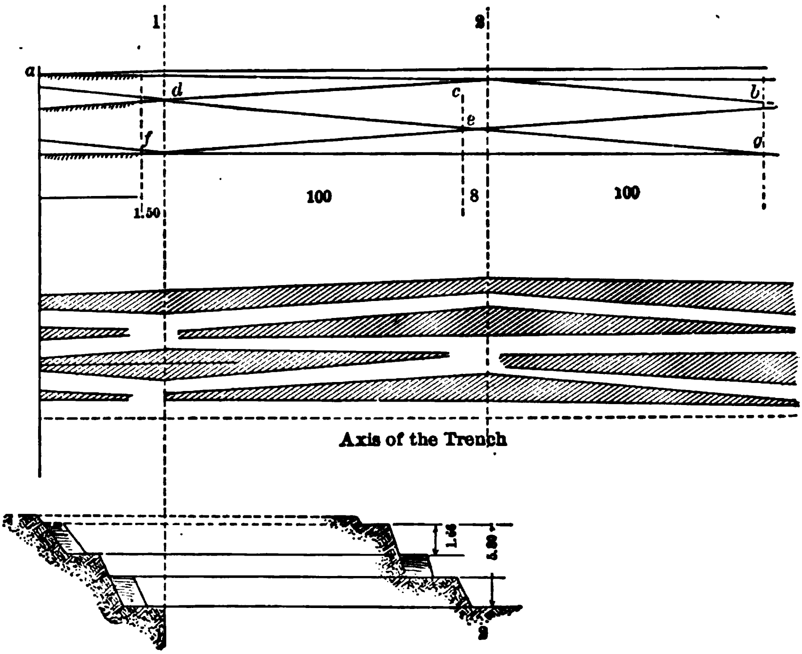
In cutting trenches of small depth, as well as in the excavation of earth from borrow-pits, in which the materials used in the fills or deposited on spoil-banks must be transported in a direction perpendicular to the axis of the construction and at a distance not greater than 90 ft., the most economical way of doing the work is to loosen the earth by hand-tools and haul the excavated materials by means of wheelbarrows.

A distinction, however, should be made in the cutting of trenches on side-hills. Here the distance from the cuts to the spoil-banks or fills is so short that the excavated materials can be easily deposited by a throw of the shovel. The work in such a case does not afford any difficulty. One man with a pick will do the loosening, while another man with a shovel will throw the excavated materials to the required point. Laborers can be placed every 10 ft., and even at a smaller distance apart, along the axis of construction.

In excavating trenches by hand where the material is transported by means of wheelbarrows, two cases may happen: either

the materials must be deposited alongside the edges of the cuts in a direction perpendicular to the axis of the construction, or the materials are used to make fills along the road.

When the excavated earth is deposited on spoil-banks located perpendicularly to the axis of the road, the work can be arranged in the manner indicated in Figs. 145, 146, and 147. Fig. 145 represents the longitudinal profile of the trench, Fig. 146 repre-



FIGS. 145, 146, 147.

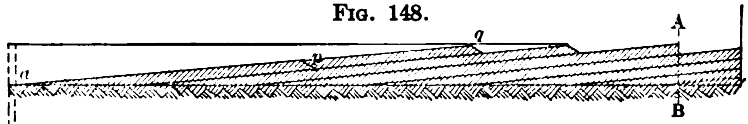
sents the plan, the two other figures being the longitudinal and cross-section of the trench respectively. The work is arranged in the following manner: The trench is divided into sections of about 100 ft. each; on every section a gang of laborers is employed, acting independently one gang from another. Each section is separated from the succeeding one by means of a horizontal bench 5 ft. long, left so that two laborers with wheelbarrows may pass on this platform without interference. The work

begins with the excavation of the soil for a depth of 1 ft. or $1\frac{1}{2}$ ft., and the material is deposited in a direction perpendicular to the longitudinal axis of the trench. But as the work progresses, in order to reach the bottom of the excavation, it is necessary to have inclined roads. These are obtained by excavating the ground on a double incline from each platform. The excavation is carried down to a depth which depends upon the inclination of the road. It has been already remarked that when the transportation of excavated materials is done by means of wheelbarrows, the inclination of the road should not be greater than $\frac{1}{12}$; consequently on 100 ft., which is the length of the working sections, the inclination of the road should not be greater than $\frac{100}{12}=8$ ft., or in other words on each road only a depth of 8 ft. is reached. When the ground must be excavated to a greater depth, at the foot of the inclined road is left another horizontal bench 5 ft. wide, and then the excavation is carried down on an incline parallel to, but in the opposite direction from, the former one. At the foot of this second incline a depth of 16 ft. will be reached. In case the excavation should be carried to a still greater depth, at the foot of this second incline another 5 ft. wide horizontal bench is left, and another incline started with its direction opposite to the second and equal to the first of the inclined roads. The work proceeds in this manner until the bottom of the trench is reached, and then the various inclines are removed, beginning with the lower ones.

When, instead of excavating a trench, an embankment must be formed with the materials taken from a borrow-pit, the work can be arranged in the manner indicated in Figs. 148, 149, and 150, in which Fig. 149 represents the plan, Fig. 148 the longitudinal profile, and Fig. 150 a cross-section of the embankment taken along the line *AB*. These clearly show that the embankment is formed by different strata of earth of equal thickness placed one above the other, and with the inclination of the temporary incline built for the access of the wheelbarrows, their horizontal projection is in the form of a trapezium. Thus, for instance, if the top of the embankment has a width of 30 ft., with a slope of

$1:1\frac{1}{2}$, and is 12 ft. high, the inclines having a grade of $\frac{1}{12}$ the height of such a trapezium will be $12 \times 12 = 144$, and the bases will be 30 and 66 ft. respectively. The stratum in formation does

FIG. 148.



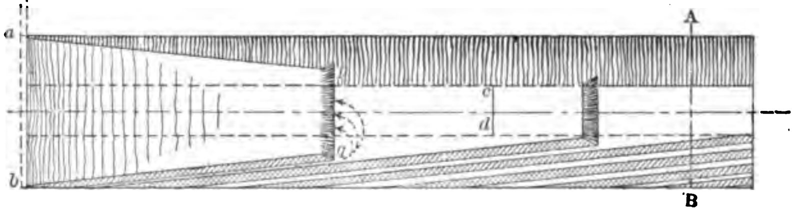


FIG. 149.

not prevent the simultaneous construction of other strata overlapping each other. When the work is completed the longitudinal profile of the top of the embankment will be in the shape of a

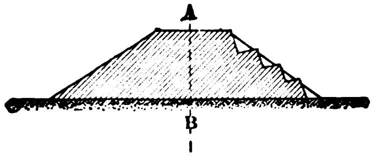


FIG. 150.

saw. Such an arrangement of the work, however, does not allow that freedom of action of the various gangs of laborers working at the different strata which is permitted with the arrangement described in the previous example.

When the hauling is done by means of wheelbarrows, it is necessary to arrange the work in such a manner as to give continuous work to the men. The number of wheelbarrows to be employed must be such that a wheeler as soon as he arrives at the loading place will find a wheelbarrow already loaded, while the shoveler will always have at hand a wheelbarrow to load. The time employed by a wheeler to go a distance, *d*, should be the

same employed by the shoveler in loading a wheelbarrow. This distance d is called a relay, and its length depends upon the speed of the wheeler and the capacity of the barrow.

In a ten-hour day's work a shoveler may load 20 cu. yds. or $20\times 27=540$ cu. ft.; the capacity of wheelbarrows being 3 cu. ft., a shoveler will load 180 barrows in a day. The time t required to load each barrow will be $\frac{36,000}{180}=200$ seconds. Now a man with a load may easily travel 10 miles per day on horizontal roads and consequently the length of the relay will be given by

$$\frac{52,800\times 200''}{36,000''}=2d=290 \text{ ft.} \quad \text{and} \quad d=195 \text{ ft.}$$

But when the grade is ascending, the greater will be the effort and the smaller the efficiency of the work which may be reduced to only two-thirds. The length d of the relay will also be reduced to one-third, and will be 130 ft.

From these simple calculations the number of men to be employed can be easily deduced, which is as many shovelers as there are relays in the distance. Thus, for instance, if the earth should be dumped 300 ft. away, or 1½ relays, it is necessary to employ 1½ wheelers for each shoveler, and if the work is so wide that it allows 8 men to work with the shovel, they will provide continuous work for 12 wheelers. If the earth is so strong as to be classified as two-man earth, the number of laborers required for the work will be 4 men at the pick, 8 shovelers, and 12 wheelers. The work done at this attack can be assumed at 160 cu. yds. of earth measured loose, or 120 cu. yds. measured in the cut.

When the excavation of the earth is done by hand tools and the hauling by wagons, the work can be considered under two different aspects—viz., the cut is above the ground-surface so that the cars have access to the front by travelling on the newly made plane, or else the cut is below the ground-surface as in the excavation of cellars or the foundations of high buildings or in wide trenches for subways, etc. In both cases the work is very simple, the only difficulty being in the arrangement of the work so

as to employ men and wagons in such a number that neither the men nor the wagons remain idle for a single instant. Each attack should be considered independently from any other, and on each one the workmen should be divided into two gangs—one composed of men with picks to remove the earth from the bank, and the second of shovelers that will load the wagons. The success of the work will depend upon the employment of the most convenient number of men and wagons in the case considered.

The number of men to be employed in breaking down the bank of earth will depend upon the quality of the soil and the height of the cut. It should be directly proportional to the consistency of the soil, and inversely proportional to the height of the cut. The earth is sometimes classified as one man, two men, etc., which means that one man can remove such a quantity of earth from the bank as to give continuous work to one, two, three, etc., shovelers. Or what is the same, a man can break down a quantity of earth from the bank in the same length of time that one, two, three, etc., men can shovel it into wagons.

But the quantity of earth removed by means of the pick depends also upon the height of the cut. The smaller the height the greater will be the effort, while with greater heights a larger quantity of earth can be battered down, because the men can facilitate the excavation of the earth by undercutting the bank at first, and then causing its fall by means of wedges or levers. In any case it will not take a long time and study to observe if the men employed at the excavation are removing from the bank the total quantity of earth required for the day's haul.

It is more difficult to decide what is the most convenient number of men to be employed for loading cars at each attack. It is a common practice among contractors to employ as many shovelers as possible around the wagons; the result is that the men often interfere with one another and their work is not very efficient. The writer has watched very carefully the loading of wagons in the construction of the New York subway on one of the sections where the work was carried on very successfully and was highly praised by the engineers; 12 men were employed in

loading a wagon, and it took them between five and six minutes to shovel the earth into a wagon of 1½ cu. yds. capacity, and it took nearly two minutes to have the loaded wagon leave the place and an empty one ready for loading. In the average 7 wagons per hour were loaded; in ten hours' work the 12 men could load 105 cu. yds. or about 9 cu. yds. each, which the writer does not consider at all a good day's work. Besides when the haul is long, it is almost impossible to have the cars always at hand succeeding each other with the regularity of a working machine, and this will still further reduce the efficiency of the shovelers.

By shortening the time for loading the wagons, the larger will be the quantity of material hauled in a day, and since the time for loading chiefly depends upon the number of shovelers, it will be of great advantage to know what will be the most efficient number of shovelers to be employed. It will be impossible to give an answer that will fit any case, but the peculiar conditions of the work and locality should be carefully examined. In many cases the wagon is placed alongside the heap of excavated earth and then the number of shovelers should be greater on one side of the wagon than on the other. As a rule, if the men are too crowded they will not work satisfactorily. A man needs at least 2 ft. space in order to work easily with the shovel. He should be placed in a position perpendicular to the sides of the wagon, whose dimensions are usually 7×4 ft., so that no more than 4 men should be placed along the longer sides of the wagon, and only 2 at the rear. To allow the men to work with comfort, thus obtaining the greatest efficiency from their work, only 10 men should be employed in loading a car when it can be located in such a way as to be surrounded on every side by the heap of removed earth. But in case the wagon may be located so as to have the earth only along one side and at the rear no more than 6 men should be employed.

The question may be asked, is it more convenient to increase the number of shovelers, or to decrease the number of wagons? As a rule it can be said that the most economical work is obtained by employing a smaller number of wagons served only by

few men, than a larger number of wagons served by a crowd of men, except in cases in which the work should be completed in a short time, and then the rapidity is the most important item to be considered even at the expense of economy in cost.

The number of wagons to be employed in the work should be calculated by taking into consideration the following items:

(1) The time required for loading the wagons, depending upon the number of shovelers employed. Thus in the case mentioned above the time for loading the cars was six minutes, and considering that it will take another minute to move the wagon and get another into place, seven minutes in all were spent in loading it.

(2) The number of wagons to be employed depends also upon the time employed in hauling the load from the point of excavation to the dumping-place. The time employed is the result of the two elements—the distance of the haul and the speed of the wagon. The former varies and is easily determined by means of one of the various methods indicated for finding out the mean distance of haul; the latter is generally assumed to be 3 miles per hour.

(3) The time required for unloading the wagon, which is usually assumed as varying between one-quarter and one-half the time employed for loading.

(4) The time for the return trip, which is considered as equal to the time employed by the wagon when loaded to travel the distance, in order to compensate for accidents met in the road and some unavoidable losses of time.

The time taken by items (1) and (3) is constant, whatever the distance of hauling may be, while (2) and (4) depend upon the distance. In the case referred to above, assuming the dumping-place located at 3000 ft. from the excavation, it will take seven minutes for loading, twenty minutes to reach the waste-banks, three minutes for unloading, and twenty minutes for the return trip—fifty minutes all together. Dividing this number by 7, the time employed by the men in loading a car, we shall have $\frac{50}{7}=7$, the number of cars required to give continuous work to the shovelers.

In general the number of cars will be given by the formula

$$N=\frac{t+2T+u}{t},$$

in which t = time employed for loading a wagon;
T = time employed for reaching the dump;
u = time for unloading $\frac{1}{4}$ or $\frac{1}{2}t$.

From this formula is easily deduced the great convenience of employing dumping-wagons which can be dumped while the wagon is in movement, since they eliminate one of the quantities in the numerator.

The cost of the excavation of the unit of volume of the material is given by the sum of the different quantities divided by the total amount of earth hauled in a day. The different items entering into the calculation are (*a*) the cost of removing the earth from the bank, which is given by the wages of the men employed in such an operation, whose number depends upon the consistency of the soil; (*b*) the cost of shoveling the earth into the wagons, given by the wages of the laborers, whose number should be fixed by the engineer according to the various conditions of the locality; (*c*) the cost of the hauling, which depends upon the distance, and (*d*) the cost of unloading the wagon.

Considering the case referred to above, in which 12 men are employed in loading a wagon, the distance of hauling being 3000 ft. and the quantity of earth transported 105 cu. yds., and assuming also that the wagons employed are of the contractor's dump type, and the consistency of the soil is three men, the cost of a unit of volume of the earth excavated and hauled away will be as follows:

4 men at the cut	$1.50	each	= $6.00
12 shovelers	1.50	"	= 18.00
7 wagons, cost of hiring	5.00	"	= 35.00
Total cost			$59.00

$\frac{59.00}{105}=.56$, cost of the excavation and haul per cu. yd.

In case only 6 men are employed in loading the cars, working easier, they will shovel not less than 12 cu. yds. per day each, or 72 cu. yds. in a ten-hour day's work. They will spend twelve minutes in loading a wagon of 1.5 cu. yds. capacity, and for the same distance of 3000 ft. it will require five cars to give continuous work to these men. The earth being of the same tenacity, the cost per cubic yard will be deduced as follows:

2 men at the cut..........	$1.50	each	=$3.00
6 men at the shovel.......	1.50	"	= 9.00
5 wagons, cost of hiring.....	5.00	"	=25.00
Total cost.........................			$37.00

$$\frac{37.00}{72}=.51.$$

By comparing these two figures it can be seen that there is no such great economy in increasing the number of men for loading a wagon as is commonly believed; the only advantage is in the quantity of earth removed in a day. When the bank is wide enough to allow different gangs to work at the same time and without interfering with one another, it will be more convenient to form gangs of shovelers of a reasonably small number of men instead of crowding them around the wagons.

The manner of directing the work when the cut is above ground does not present any difficulty. The wagons travel always at the level of the road and over the newly excavated plane, and go always nearer and nearer the front. To allow the wagons to easily turn, it is necessary to have a space for loading as wide as possible, and it will be convenient to divide the work into different attacks, having at each one a separate gang composed of only a few men, instead of having only one gang made up of a great many men. Each gang should be provided with its own wagons, whose number should be in proportion to the number of shovelers in the manner already explained.

In case the cut is below the ground-surface, as usually happens in digging cellars or wide trenches for subways or other purposes, the work begins with the excavation of the soil, following an in-

clined plane with such a grade that it can be easily overcome by horses and wagons. When the plane of the excavation has been reached, the same number of men is employed in cutting the front of the bank forward, while the same gangs of shovelers will load the earth into the wagons as before. But other men will be employed in working in the opposite direction, cutting part of the wide incline which was at first used. In this manner only a portion of the incline will remain, and will be left of such dimensions that it will afford an easy passage to two wagons going in opposite directions and without interfering with one another.

This inclined road is the last portion of the earth to be cut, and it is removed only after all the work of excavation has been completed. The cutting of this inclined road is done in two different ways, depending upon the implements at hand. If on the work there is a hoisting-machine to be used afterward in connection with derricks or cableways, it may be used for hauling the wagons up the incline. Then the road is sliced up so as to make it steeper with every slice of earth taken away, and the wagons are pulled up by the rope connected to one of the reversible drums of the engine and attached to the shaft of the wagon. When the road becomes very steep, it is removed by cutting it in benches, one above the other, and 2 or 3 ft. wide each, and throwing the material to the ground-surface, from where it is loaded into the wagons.

When there is no hoisting-machine, the inclined road is removed by cutting it up in benches of different heights. This means that the earth is cut in parallel vertical slices and the material is loaded directly into the wagons, which will stand on the edge of the cut. With the progress of the work and when the cut has reached such a height that this is no longer possible, then the height of the cut is divided into two benches. The earth removed from the lower bench is thrown on top of the same bench, where stand shovelers that throw the same earth on the wagons which stand on top of the upper bench. Recesses of 2 or 3 ft. are left between the various benches, and in this manner the earth is shoveled two or more times before being hauled away.

CHAPTER XXI.

THE DIRECTION OF EXCAVATION WORK (CONTINUED).

THE manner of excavating earth by hand-tools and removing it by means of industrial railways hauled by horses is convenient for excavations of less than 30,000 cu. yds. of earth and for distances not over 2 miles. The excavation of the earth from the bank is done in the same way as if the hauling were done by means of wagons. It is very important to have such a number of men at the bank as will cut down the required quantity of earth without the shovelers and cars waiting for them.

The manner of arranging the tracks and how to form the embankments will be discussed later on. When the excavation of the earth is obtained by means of powerful continuous and intermittent digging-machines, the arrangement of the tracks both at the front and at the dumping-place requires the greatest attention on account of the large quantity of material excavated and dumped in a day. The tracks must be moved continuously, and yet built with great solidity, so as to stand the heavy traffic of the road. This does not happen with industrial railways, especially when hauled by horses. Here will be given only the manner of fixing the number of horses, the number of trains, and the number of cars of which each train should be composed, so as to give continuous work without any loss of time; and also the various methods of cutting the trenches, as well as the manner of calculating the cost of the transportation of the unit of volume of the material.

It is assumed that the capacity of the cars is 1 cu. yd. each, and the rails are placed on horizontal roads or with an inclination

less than 3 per cent., and that the speed of the horses in hauling a train will be $2\frac{1}{2}$ miles per hour. On these conditions a horse, it is assumed, can haul five cars.

The number of horses, H, required to haul a train of n cars of the capacity of c cu. yds. and weight w is given by the formula

$$HT = n(cm + w)(g \pm i),$$

where T is the mean hauling efficiency of a horse working ten hours a day, m is the weight of 1 cu. yd. of the excavated material, g is the resistance of friction of the rails, and i the inclination of rails. The sign $+$ is for the ascending roads, and the sign $-$ when the road descends from the point of excavation toward the filling embankment or dumping-place. N, being the number of trains required for the continuity of the work, is found in the same way as the number of wagons required in the work when the earth is hauled by means of wagons. It is obtained by dividing the time employed in the round trip by the time employed in loading the train, including in the round trip also the time for loading and unloading the cars, or

$$N = 1 + \frac{\frac{2d}{v} + t_1}{t},$$

where d is the distance of hauling, v the velocity in feet per hour, t time employed in loading a train, t_1 time required for unloading the train.

The number of cars required for continuous work depends upon the volume Q in cubic yards of the whole excavation, and upon D, the number of days in which the work should be done; also the number h of working hours per day, upon the distance d, the velocity v of the hauling, and upon the time t and t_1 employed in loading and unloading. The number of cars, C, to be loaded every day is given by $\frac{Q}{Dc}$, in which c represents the capacity of each car. But since each car is loaded several times a day,

according to the distance of hauling, the number of cars to be employed in the work will be given by the formula

$$C=\frac{Q}{Dch}\left(t+\frac{2d}{v}+t_1\right).$$

C being the number of cars required in order to have continuous work, the number of cars n for each train will be given by

$$n=\frac{C}{N}=\frac{Ct}{t+\frac{2d}{v}+t_1}.$$

Consequently the work should be arranged with a number of horses,

$$H=\frac{Q}{DcTh}(cm+w)(g\pm i);$$

with a number of cars,

$$C=\frac{Q}{Dch}\left(t+\frac{2d}{v}+t_1\right);$$

with a number of trains,

$$N=1+\frac{\frac{2d}{v}+t_1}{t};$$

and each train provided with a number of cars,

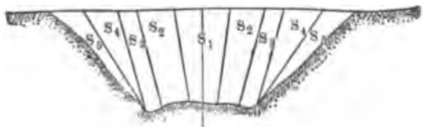
$$n=\frac{C}{N}.$$

The cutting of the trenches for roads and railroads, besides the usual manner of attacking the bank at the front for the whole width of the trench, can be made also in two different ways, known as the open-cut and the English method.

The open-cut method was in great favor with engineers and contractors some time ago, but it is now nearly abandoned; it is given here because in some particular cases it may be found

useful even to-day. Figs. 151 and 152 show the plan and longitudinal section of a trench. Along the longitudinal axis of the trench is opened a cut for the whole height of the trench. The width of the cut is such as to allow the passage of cars and its

FIG. 151.



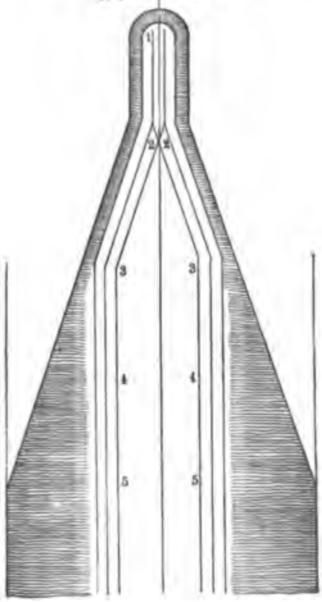
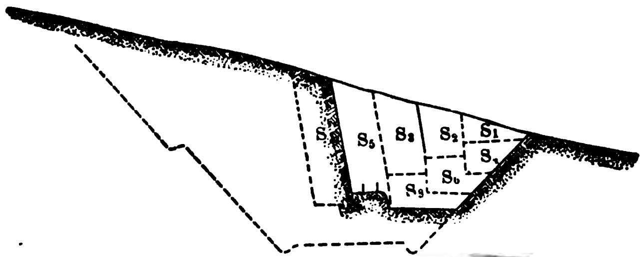


FIG. 152.

sides are left as vertical as possible. On the bottom of this cut, corresponding to the plan of the proposed road, is laid the track. The cut is widened afterward by means of the lateral excavations marked S_2, S_3, S_4, etc., in the figure, and each cut has its own point of loading. As soon as the parts S_2 are excavated the track is shifted into two lines, each one being close to the excavation, so that the work is served by a double-track line except on parts 1 and 2, where there is only a single-track line for hauling

the earth excavated at parts 1 and 2. The congestion of cars at the front prevents all gangs from working continuously, because they have to stop while the trains are manœuvring, and for this reason this method of cutting trenches is expensive and slow.

FIG. 153.



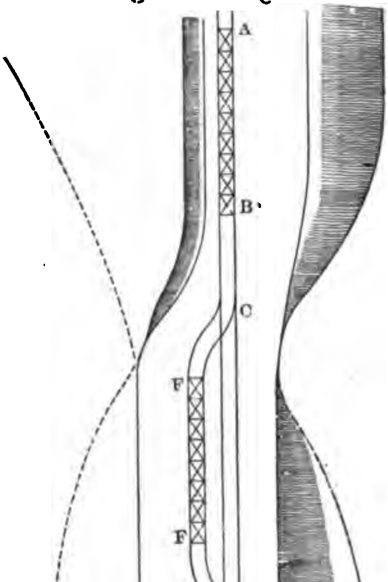


FIG. 154.

A similar method, but one affording greater convenience, is the one indicated in Figs. 153 and 154. It consists in opening at first a narrow trench along the longitudinal axis of the cut. On

the floor of this trench, whose depth is very shallow, is placed a single-track line, and the excavation is then made on the part marked 2 in the figure and is carried down to such a depth that it is no longer possible to load the cars. After this cut has been made the track is removed to the bottom of excavation No. 2, and the cars are loaded with the earth taken from the cut marked 3 and 4 in the figure at the right and left of the track. When the excavation of these two parts is completed the track is lowered to the floor of cut No. 3 and the earth is taken from parts 5 and 6, and when these are entirely cut, the track is lowered again to the bottom of trench No. 5 and the earth is excavated from parts 7 and 8, etc.

The arrangement of the tracks along the longitudinal axis of the construction is indicated in Fig. 154. The work begins by laying the track in Section 1 with an inclination very close to the ground-surface, which in some cases may be very steep. With the consecutive excavations the inclination of the road is changed until a convenient one is obtained for the cars employed to haul the earth. Such an inclination begins to be convenient in the excavation of Section 5 and the following until the floor of the trench is reached. On this the loaded cars may easily slide down the incline and perhaps haul up the empty ones, or these can be otherwise easily hauled up. The descending of the loaded cars along steep roads is, however, very dangerous, and if they are not provided with brakes some means should be devised to prevent their running away in the manner described in hauling the material on inclined roads.

The lowering and removing of the track from one section to another can be performed in different ways, depending chiefly on the quality of the soil and the particular conditions of the locality. Thus, in the case considered above, after the corresponding cuts have been made, the tracks must be not only lowered, but also transferred horizontally. When the soil is very loose or wet on account of percolation of water, the moving of the track is obtained by means of several men working along the line and pushing the track with iron bars. The track will reach its new

position by sliding along the slope which was left for the former embankment and upon which the track stood. But when the soil is dry and resistent so that the sides of the cut are nearly vertical, the track is lowered and then transferred horizontally to its new position. In such a case the earth under the track is removed until only a few pillars are left to hold up the track; then props are inserted and the pillars of earth cut down. By removing the props the track will fall on the floor of the excavation, from where by means of levers it can easily be transferred to the required place.

The arrangement of the cars at the point of excavation must be such as to insure continuous work both to the men and machines, in case these are employed, for the removal of the earth. This is a very important item to be considered, especially in works of great magnitude; then it is necessary to dispose the tracks in such a way that a train of empty cars may immediately take the place of the ones whose cars have just been loaded.

When the work is in side hill, as in the excavation of the trench given in Fig. 153, the simplest arrangement of the tracks is that indicated in Fig. 154, where a track *AB* is located at the foot of the slope and on the floor of cut 5 where the men are working. At a short distance from the point of excavation it is necessary to have a side track for the service of the trains. The empty train enters the track *EF* and stops there, while either the horses or the locomotive haul the loaded train along the track *AB* to a point beyond the switch *C* on the main track. Then the empty train is hauled back on the main track and enters the track *AB*, bringing the empty train to the point of hauling.

In many cases the bank is attacked at several points along the front and then more than one train may be loaded at a time. The convenient arrangement of the track is the one indicated in Fig. 155. The main track is produced as far as possible, and finally it turns to reach the bank at the most advanced point where the train *AB* is loaded. Along the main track is placed a switch with a side track *EF* for the loading of another train. Also in this case along the main track it is necessary to have a

switch with a side track *CD* for the service of the trains. Such an arrangement affords independence to the trains which will be operated in just the same manner as indicated above.

Another manner of cutting trenches is according to the English method, which was at first commonly employed in England in the construction of railroads, and followed afterwards on the continent, but is nearly abandoned now. Along the longitudinal axis of the construction and close to the floor of the proposed

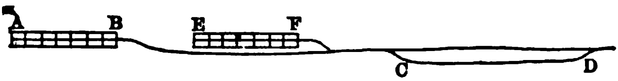


Fig. 155.

excavation a heading was excavated. The dimensions of this were such as to allow the passage of a train running on a narrow-gauge track. All along the line and just above the heading shafts were sunk and communication established between the ground-surface and the heading. The shafts were afterwards enlarged in a funnel-like shape throwing the material inside the shaft, and this filled the cars that were ready there. The loaded cars were removed, and another train of empty ones took their

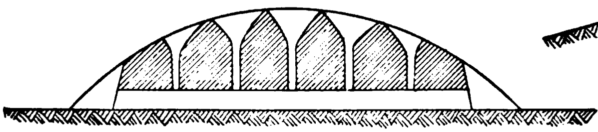


Fig. 156.

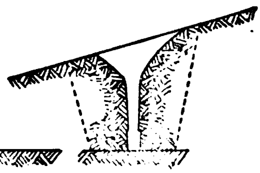


Fig. 157.

place and were ready to be filled. In this manner the expensive cost of loading the cars was dispensed with. The dimensions of the heading were 6×7 ft., while the shafts were 4 ft. square. Other advantages of this method are the rapidity of the work, and that the track is placed where it serves for all the work without the necessity of removing it. Besides, the heading being excavated at the lowest point of the work, it served as a drain. But the great cost of the excavation of the heading makes this system objectionable, especially when the cut is not very deep.

Figs. 156 and 157 show the longitudinal profile and cross-section of a trench excavation according to the English method.

The cost of the unit of volume of the work as obtained from the working expenses is deduced from the following items:

(*a*) The cost of excavation.

(*b*) The cost of loading the cars.

(*c*) The cost of the motive power.

(*d*) The cost of unloading the cars.

These are very easily calculated without the necessity of introducing complicated formulas or having recourse to difficult algebraic solutions. But it is necessary to remember that the cost as given by these items is not the real one, since it does not include the interest of the capital invested in the cars and road; the cost of maintaining the road in good working order, of setting up the plant at the beginning of the work, and of removing it after the work is completed; the expenses for lubricating the cars and repairing both the tracks and cars, and all the other expenses, including the sinking fund. Some of these items are easily deduced from the cost of the plant, as, for instance, the interest of the capital and sinking fund. The repairing is calculated per annum at one-fourth of the total cost of the cars and tracks, and by dividing this sum by the total quantity of earth hauled in a year is found the quota to be added to the cost of the unit of volume for repairing. The cost of the maintenance of the road is usually given by the wages of the men employed for this purpose, and the cost of setting up and removing the road is generally assumed at 15 or 20 cents per lineal foot.

In excavations of great magnitude the earth is removed by machine, and the transportation of the excavated material is usually done by trains composed of ordinary railroad cars running on standard-gauge tracks and hauled by locomotives. The direction of the work in such a case is very difficult, and it will be almost impossible to indicate rules in regard to the manner the work should be directed. Every work can be done in different ways, but the selection of the most convenient in the peculiar case the engineer has to deal with depends upon many circum-

stances, chiefly on the local conditions of the work and the machines employed. In any case the engineer should do the work in the simplest way and with the smallest effort, which will result in obtaining the work at the smallest cost. This generally is accomplished by selecting the most efficient excavators; by a rational sequence of the various cuts required for opening the trench; by the most convenient and economic location of the tracks; by the employment of only the number of cars and locomotives strictly necessary for the work; by the proper formation of trains; by facilitating the unloading of the cars at the dumping-place, and by looking to everything, even to the smallest details, so as to have the work run with the regularity of a machine.

The greatest attention should be devoted to the selection of the most convenient excavating machines required for the work. In the description of the various excavators it was said that both the continuous and intermittent machines will dig either above or below the plane of the embankment upon which the machine stands. With the exception of the grabbing-bucket excavator, which is able to dig the earth from any depth, all the other machines excavate the earth to a limited height only so that when the trench to be cut is very high, it is necessary to cut it in several sections one above the other. This will require the removal and lowering of the trackway several times, an operation which involves heavy expense. In such a case it will be useful to employ different kinds of machines for the various sections into which the cut is made. Thus, for instance, it will be convenient to employ a steam-shovel for cutting the earth for the first 15 or 20 ft. in height, and to remove the material on trains running on tracks laid on the floor of the cut. The steam-shovel should be followed by a down-digging machine, either of the continuous or intermittent type, and the material loaded onto trains running on the track previously laid on the floor of the first cut. In this manner the cost of removing the tracks will be greatly reduced, and such an arrangement is liable to yield fair profits to the contractors. But it requires the employment of different kinds of machines, and consequently the necessity of having a larger and

expensive plant, besides the inconvenience of having two gangs of men operating and working in an entirely different way, and it will be very difficult to make these various appliances work harmoniously, especially if the trench does not extend to a great length. All the advantages and disadvantages should be carefully examined, and selection should be made of the method which, in the particular case the engineer has to deal with, will afford the greatest advantage.

In regard to excavators, American engineers have very little to select from, since the only excavator commonly employed in this country is the steam-shovel. It is, and has been, so extensively used that the operators have acquired such an experience in its handling that they usually obtain results not very far from the technical efficiency of the machine.

The sequence of the cuts in the trenches as well as the arrangement of the tracks for hauling the materials excavated by means of the steam-shovel have been so fully discussed by Mr. E. A. Hermann in his book, "Steam-shovels and Steam-shovel Work," that it will be better to refer the reader to this book than to attempt to give here an incomplete description of the various cases he has considered. It is necessary to remark that these are not the only ones encountered in the work of excavation, nor is the indicated manner of excavating and hauling the only one which may be employed in such a case. Here only three cases are considered, the widening of a cut when the material is loaded on the main track; second, cutting down grades; and third, opening new trenches for construction works. All of them are deduced from the book of Mr. Hermann.

Widening a Cut.—The manner of doing the work is clearly indicated in Fig. 158. A switch is put on the main track just beyond the end of the cut and far enough away to permit the steam-shovel to load the cars on the main track. Very often in the beginning there is not much room for the machine, and then the bank is at first attacked by hand-tools and the earth removed by means of wheelbarrows. Such a work is carried on until a side track for the machine can be placed on the floor

of the excavation. Through the switch of the main track the machine is brought in front of the bank of earth to be removed and is ready for work. Strings of ten to twenty cars are then drawn along the main track and stopped opposite the machine for loading. This machine as it works advances, and when it has reached

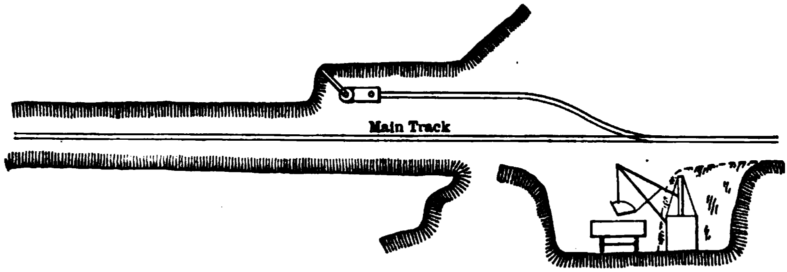


FIG. 158.

the end of the switch it advances on short sections of track generally 4 ft. long, which are placed in front of it and again taken from its rear, when it has moved forward. After all the cars have been loaded they are taken away for unloading. Sometimes the steam-shovel is left idle until the train returns, which is a very wasteful method of working, even where the haul to the dump is short, half a mile to two miles. Two engines and crews should be used for hauls up to ten miles; three engines and crews or more for longer hauls, or where the traffic on the main line is very heavy and delays to the work-trains are frequent, the material is generally utilized in filling trestles, widening embankments for side tracks, double tracks, yards, etc., thereby making two improvements at the same time.

Cutting Down Grades.—Suppose that the grade of the road is to be lowered in the manner indicated in Fig. 159. From a switch inserted on the main track at grade the machine advances, cutting the portion marked 1 and loading the cars standing on the main track. As it cuts it moves forward on a track laid on the floor of the pit, which is usually 2 ft. below the plane of the main track. The steam-shovel cuts its way and advances continuously until the cut has been made for the whole length of

the knoll, and then the track, which in this case was built continuous instead of in small sections as before, is switched to the main track. The machine is brought back again on the main track and the new track will now be temporarily used by the trains as main track. The machine will begin to cut No. 2, loading the materials into the cars running on the temporary

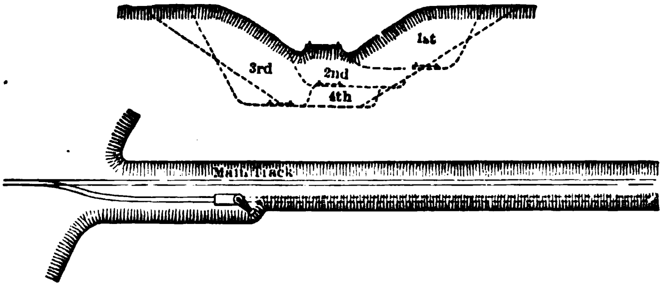


FIG. 159.

main track on the bottom of pit 1. The cut is also made for the whole length of the knoll, and the track laid for the machine will be the permanent track of the new road. The machine is brought back again, cutting the portion of trench No. 3, loading the cars running on the tracks of pit 2. When also this portion has been cut the slopes are adjusted by cutting the parts limiting the top of the slope, using the materials for the fillings of the lower portion of the same slope.

Construction Work.—In the construction of new roads it is necessary sometimes to cut wide and deep trenches, and the work is done on small sections at a time. Suppose we have to cut the trench given in Fig. 160. The cut will be made at different times and in the order marked in the figure. The work begins with the excavation of portion 1 and the material is hauled away by cars running on a track temporarily placed on top of the surface-ground and close to the edge of cut 1. While the machine advances cutting its way, on the bottom of pit 1 is placed a track upon which the trains will pass when the machine is cutting portion 2. The work will be continued in the same way, always building up a new track for the machine, while the

trains will pass on the track previously built for the machine when cutting the preceding portion. The work is arranged in several portions, and when all are excavated the whole trench is opened to the required depth and dimensions. The success of the opera-

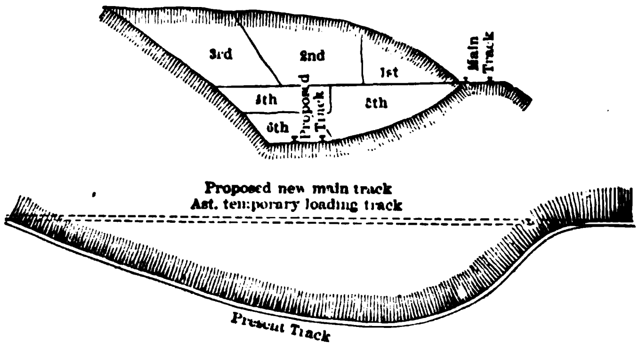


FIG. 160.

tion depends upon the sequence of the cuts and the rational arrangement and connection of the tracks.

Difficulties, however, are liable to be encountered, especially in the excavation of part 1, when cutting knolls. These are chiefly due either to the inclination of the surface-ground or to the differences in depth between the floor of the pit of the first cut and the surrounding surface-ground where the track for the removal of the material is located. The first inconvenience is usually avoided in different ways, depending upon the condition of the locality. Sometimes light railroads are used, either hauled by horses or by ropes in the manner described for hauling materials on inclined roads when the slope of the knoll is great, or by removing the material from cut 1 by means of wagons. The second inconvenience is avoided by raising the track upon which the machine advances, and this is obtained by a cribwork. After the excavation of part 1 is completed and the machine is brought back again so as to begin the cut of portion 2, the cribwork is removed and the track for the trains will now rest on the floor of pit 1.

The train must be formed so as to be in proportion with the

force of the locomotive, and yet to obtain the greatest efficiency by using the smallest number of cars possible, without interfering with the continuity of the work. If the total number of cars is such that they can be hauled by only one locomotive, it will be better to have only one train. After loaded, it is immediately hauled to the dumping-place and unloaded, returning right away to the point of excavation to be loaded again. In many cases, however, notwithstanding it is possible to haul all the cars in one train, the loss of time will be so great that the work will not be completed at the appointed time; it will be more convenient to use two locomotives of smaller efficiency and form two trains, each having a number of cars half of the total number required for the work. In this case the trains will alternate at the excavation and at the dump, and the service of locomotives must be arranged in such a way that the stops of the trains at the extreme points will last only the time required for the loading and unloading of the cars. Otherwise, to compensate for the loss of time without using another locomotive, it should be necessary to increase the number of cars, and this addition will tend to increase the cost of the work without any useful practical return.

If the time $\frac{2d}{v}$ employed by the train in its round trip is equal to the time t required for loading another train, and equal also to the time t_1 for unloading the same train, it is necessary to have three trains, each one composed of $\frac{C}{3}$ number of cars, where C is the total number of cars required for the excavation.

The number of trains required for the work is given by the formula

$$\frac{1}{t}\left(t+\frac{2d}{v}+t_1\right),$$

and each train will be composed of a number of cars,

$$n=\frac{Ct}{t+\frac{2d}{v}+t_1}.$$

The total number of cars to be employed depends upon the time allowed by the specifications to complete the work, and this will guide also the engineer in ordering the number of excavators to do the work in the required time. The number of cars is given by the formula

$$C=\frac{Q}{Dch}\left(t+\frac{2d}{v}+t_1\right).$$

In regard to the arrangement of the tracks to the dumping-place for the formation of the embankment, it could be said that the embankments to be solid and resistent should be made of various strata as thin as possible. These strata should be as horizontal as possible, and they are constructed in the following manner: Beginning at the point at grade is built up at first a narrow embankment as high as the first stratum and formed by dumping the cars from their front ends. Upon the track that is laid on this embankment and advanced with it are run the trains that dump the material sideways, thus enlarging the filling for the whole width of the embankment. The track is continuously moved so as to remain always on the edge of the filling. Then the second stratum is built up in the same manner, by forming a second narrow embankment as before by dumping the cars from their front end and continuously advancing the tracks, and it is widened in the same way by dumping the earth from the sides of the cars. In a similar manner is constructed the third stratum, and thus the surface of the embankment is reached if the successive strata are built with one-third of the total height at a time. Figs. 161 and 162 show the longitudinal and cross-section

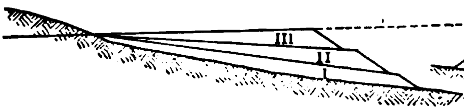


FIG. 161.

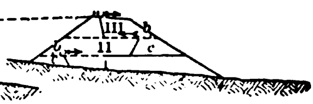


FIG. 162.

of an embankment constructed in the manner just explained. The cross-section indicates also the most economic way of moving the tracks, which are shifted from the left to the right in the first stratum, in the opposite direction for the second, and as in the

first for the third, when the whole embankment was divided into three sections built in succession.

When the embankment has a greater height, it may be built by dumping the materials at the front for the whole width of the embankments. It can be made of different inclined strata, the first ones having great slopes, and the successive smaller, until the total filling has been made and the embankment constructed to the required height, and in the manner indicated in Fig. 163. Since by operating in this way the material must be dumped

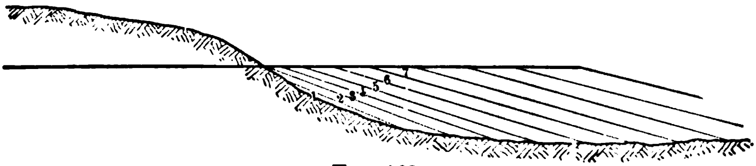


FIG. 163.

at the front, when there are no cars so constructed it is necessary to employ turntables, two at least, and they can be located as in Fig. 164, which shows also the arrangement of the tracks.

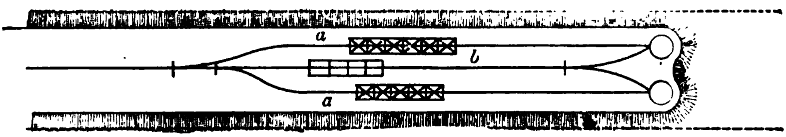


FIG. 164.

The main track is divided into two side-lines where run the loaded cars; the two turntables are provided with short section of track connected with a third central track where the empty cars are stalled while awaiting to be formed into trains. Only one turntable may be used for forming the front of the embankment, while it is widened by dumping the materials directly from the cars standing on the tracks. The arrangement of the turntable and tracks in this case is accomplished in the manner indicated in Figs. 165 and 166.

These various methods, although convenient for narrow-gauge tracks, are not convenient when the heavy cars of the ordinary railroad type are employed. The turntable must advance continuously, its weight increases with the capacity of the cars

used, and it must be removed oftener. Another inconvenience is that these heavy turntables must always remain at the most advanced portion of the newly built embankment, just on top of the slope of the dump, where the earth is so loose that it can hardly stand their weight and is liable to sink or slide down, thus arresting all the work. Besides, dumping the cars in this way requires enormous time, owing to the fact

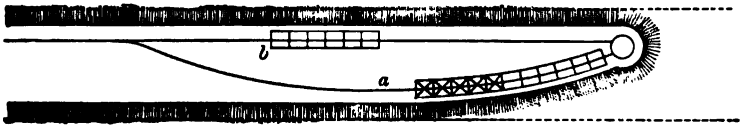


FIG. 165.

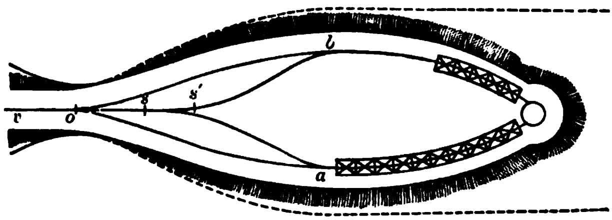


FIG. 166.

that the cars must be detached, one at a time, brought upon the platform and dumped, and then shifted back on the proper track. These various operations involve a great deal of time and expense, because several men and horses must be employed in handling the cars and forming the trains. Consequently such a method of forming embankments should be abandoned when the excavation is made by powerful machines and the earth is hauled by ordinary railroad-cars running on standard-gauge tracks, and the following system will be found then more convenient.

Along the longitudinal axis of the road is constructed a trestle with the tracks at the plane of the top of the embankment which it is proposed to construct. Upon this track run the cars that are unloaded by machine, and the earth falls below and around the trestle which will form the backbone of the embankment. The cost of the construction of the trestle is compensated for

by the rapidity with which the embankment can be constructed, by not removing the tracks which otherwise will be required, and because it allows the unloading of the cars by machine.

The unloading of the cars of the ordinary railroad type can be done by hand or by machine, according to the form of the cars used for hauling purposes. The most commonly employed are the gondola- and platform-cars and the large variety of dumping-cars already described.

The gondola-cars alone are dumped by hand. In such a case the laborers travel with the train, a gang on each car, the number of men in each gang depending upon the time the locomotive is allowed to stop. In the construction of new embankments it is more convenient to form the train with the locomotive at the rear pushing the train instead of pulling it; but when the train is running on the main track, it is indifferent whether the locomotive is at the front or rear. When the train has reached the dumping-place the men remove the board at the side of the car, and thus a great deal of material will fall, while with shovels is hastily thrown down the remainder. The train thus unloaded is brought back to the excavation to be loaded again. But the cost of unloading materials by hand is very expensive, and it is used only in connection with excavations of small quantities of earth.

The dumping-cars of the Goodwin and other types are certainly very convenient and easily handled, but they are very expensive, and the complicated parts forming the dumping arrangement easily get out of order, especially when roughly handled, as it is in connection with the excavation, in which the car has on many occasions to stand the jerks and strains of the excavators. For these reasons the dumping-cars of large capacity are very seldom used in works of excavation.

Engineers and contractors prefer to haul the excavated materials on the ordinary platform-cars used on railroads, and the great advantage of their employment is that they can be unloaded by machine. The simplest machine for unloading trains consists of a plow of large dimensions resting on the platform of the

car, and it is located at the rear end of the train. This plow is tied to one end of a wire rope whose other end is fixed to the locomotive. When the train has reached the dumping-place, the locomotive is detached and slowly moved away from the train. It will draw the wire rope, and the plow will be pulled to the front of the train; in passing along the platform it will clear it of all the materials, which will fall on the ground. When the train has been thus unloaded, the locomotive will back up, the plow will be brought to its former position, the locomotive attached again to the train, and this will be moved to the point of excavation to be loaded again. Although this manner of dumping is very

FIG. 167.

simple and preferable to any other, yet it involves a waste of time in the performance of the various operations, especially in detaching and moving the locomotive; to avoid these inconveniences, different machines have been devised. The most convenient machine used for unloading the cars is the rapid unloader, illustrated in Fig. 167, patented and built by the Lidgerwood Manufacturing Company. This consists of a plow of large dimensions placed at the rear end of the last car of the loaded train and resting upon the

platform of the car, the width of the plow being equal to that of the cars. The plow is attached to a wire rope which is commanded by a single-drum reversible engine located at the front end of the first car close to the locomotive. By putting the engine into gear the drum revolves and winds the rope which will pull the plow. This, in sliding upon the platforms of the cars, which are made continuous by steel aprons, pulls all the earth out of the car, and it will form the embankment. Plows are made to dump either to the right or left side, or on both sides simultaneously, and then they are provided with the point at the center. To prevent the plow from running out of the cars it is guided by means of small vertical pieces of timber inserted vertically along the sides of the cars and a few feet apart. The locomotive provides the steam to the engine, which exerts a direct pull on the cable of 25 tons and draws in the same at a speed of 125 ft. per minute. The manufacturers claim that the entire act of stringing the cables, fastening them to the plow, the train running a mile to the point of dumping, the plowing off of the load, and the returning to the point of starting, requires about twenty minutes. The correctness of their statement has been proved on many occasions on the works of the Delaware and Hudson Canal Company's railroad.

CHAPTER XXII.

SHRINKAGE OF EARTH; COST OF EARTHWORK.

IN removing earth from its natural bed the cohesion of its particles is destroyed and consequently it will occupy larger spaces. Its volume increases according to the nature of the soil, as was explained on p. 134. When the earth is deposited in embankments at first it remains loose for some time, but in presence of humidity and under pressure the particles are compacted so as to resume a small degree of cohesion. This produces the phenomenon of shrinkage, and more earth is required in the embankments if they have been constructed to a given level.

The shrinkage of earth has been variously estimated by different authors. Prof. Johnson, for instance, is of the opinion that earth will shrink $16\frac{2}{3}$ per cent., while Mr. H. P. Gillette states that it will not shrink more than 2 or 3 per cent. It is a very difficult task to reduce to a constant coefficient the shrinkage of earths, since it depends upon so many circumstances which are very variable and each one of which should be taken into consideration. The principal causes, however, tending to alter the shrinkage of the earths are: the nature of the soil, the condition of the weather during which the embankments are formed, and the manner in which the embankments are built.

Soils when placed in embankments shrink in a different way, according to their composition. In general it can be said that the shrinkage is inversely proportional to the looseness of the soil. The looser a soil is in its natural bed, the smaller will be its shrinkage in the embankment. This stands to reason. When a soil is loose its particles are not very close together, with voids

between the particles; and since it will swell very little when removed it will also shrink very little when placed in the embankment. Also in the case of a compact soil: in being removed many voids will be formed and the material will swell greatly, and when the earth is put on the embankment it will occupy a larger volume than in the cut, and it will shrink greatly, due to the closing of the voids. The shrinkage of the embankment depends also upon the manner in which the embankment was formed. To prevent shrinkage the embankments should be made of thin layers placed one above the other and the earth in each layer should be well rammed. In ramming, the particles of earth are driven closer together, thus leaving a small number of voids, and the shrinkage will then be almost insensible. But if the embankment is formed by dumping the material for the whole height of the embankment, numerous voids will be left in the mass, and they will slowly be filled in under the action of the pressure of the traffic on the surface of the embankment, and also on account of the water, which will tend to carry down the particles of the earth so as to fill all the voids. There is no doubt that in such a case the shrinkage of the embankment will be greater than if the embankment was built in small layers one on top of the other. Again, if, in building the embankment, the road upon which the materials to be dumped for its construction are hauled is kept always on the same spot and advanced along the same straight line, the earth underneath this portion of the embankment will be well pressed, while at the sides the earth will be looseer. If the road instead had been shifted continuously from one side to another the earth on the embankment would be equally and uniformly pressed without the necessity of ramming it. In such a case the shrinkage of the embankment will be very small.

The shrinkage of earth in newly constructed embankments depends also upon the weather in which they were built. When constructed in dry weather they will shrink more than if built in a rainy season. In embankments constructed in presence of rain or water, the filling of the voids takes place during construction, while if built in dry weather the voids are filled in afterward;

in the former case the embankment will shrink a little, while it will shrink to a great extent in the latter.

For all these reasons it seems foolish even to attempt to find out a constant mathematical coefficient for the shrinkage of various embankments. But there is even a worse error that the writer has found very common in this country. Many contractors and even some engineers believe that the shrinkage of earth is the decrease of volume of the earth in the natural bed. Thus Trautwine says that when the earth is dug, 1 cu. yd. is equal to $\frac{5}{6}$ or to 0.8333 cu. yd. in place; yet when made into embankment it gradually subsides, settles, or shrinks into a less bulk than it occupied before being dug.

In a certain town of a certain country the aldermen were discussing the project of opening a large square as an improvement to the town; but they were bothered by the cost of hauling the excavated earth, since the dumping-place was at a great distance. One of the aldermen proposed to solve the problem by opening a large hole in the center of the square and dumping there all the earth to be excavated. For many years this story has gone around, amusing the crowds, but the writer thinks now that the alderman must have been a very good engineer. In fact, if earth of the quality of puddled clay, according to Trautwine, shrinks 25 per cent., by making the hole large enough, the earth put back would have occupied one-quarter less of the former space, and consequently would have left room enough for the dumping of that required for the square. It seems ridiculous, but it is a matter seriously discussed in many books.

Shrinkage should not be calculated in proportion to the earth in the cut but on the newly built embankment. The mistake arises from the manner of calculating earthworks which is commonly employed; that is, by tolling the wagons hauling the earth that has been already excavated, and consequently whose volume had been increased. It is no wonder that in the embankments it will shrink, according to the figures given by the various authors.

Trautwine, Baker, Patton, and many others give for the shrinkages of the various soils the following figures:

Sand and gravel.		8	per cent.
Gravelly clay.	from	8 to 10	" "
Earth loam and sandy loam.	"	10 to 12	" "
Puddled clay and puddled soil. . .	"	20 to 25	" "

Since the earth in the embankment will shrink, the effect is that the top of the embankment after a while will be found at a lower level than it was constructed. To have the road at a required plane it would be necessary either to build the embankment a little higher than the proposed level of the road, or otherwise to compress the earth during the construction of the embankment so as to prevent any further shrinkage. In the construction of railroads the embankments are built a little higher than the proposed plane of the road. Each railroad has a special set of tables giving the increase to be made in the embankments as an allowance for the shrinkage, and the various data are given in proportion to the various heights of the embankments and according to the different materials entering into their formation.

The compression of the earth during the construction of the embankment can be made by hand and by machine. The tool used to ram the earth by hand is the rammer. This consists of a heavy, large piece of wood in the shape of a frustrum of a cone surrounded by iron bands and fixed to a vertical handle. The weight varies between 20 and 25 lbs., and is operated by a man who raises it and lets it fall on the earth. When the strata of earth are very thin, as, for instance, 5 or 6 ins. thick, they can be rammed very well, and the cost will be between 1 and 1½ cents per cubic yard, an item which, although very small, assumes fair proportions in the construction of embankments of great length and height.

The compression of the various particles of earth is obtained also in a more economical way by means of rollers. These, according to size and weight, can be divided into hand-rollers and rollers moved by horses and steam.

Hand-rollers consist of an iron cylinder about $2\frac{1}{2}$ ft. in diameter and provided with an axle to which is attached a handle. It is operated by a man who pushes it over the earth, and on account of its weight it tends to compress the earth and to fill in some of the voids that were left in the mass. But the efficiency of the hand-roller is very small in regard both to the pressure exerted and the quantity of work done in a day.

Rollers dragged by horses are more powerful, and consequently more commonly employed. They are similar to the hand-rollers except that they are of larger dimensions, being from 6 to 7 ft. long and about 3 ft. in diameter. Shafts are attached in some way to the axle of the roller so that it may be dragged by one or two horses. To avoid unnecessary effort in the animals in meeting obstacles and in order to easily overcome them, the roller, instead of being made of only one iron cylinder, is made up of three or more disconnected pieces. These rollers are very efficient on account of their weight; they compress the earth very well, and since the horses dragging the roller may travel from 15 to 20 miles per day, the amount of their work will be $15\times5280\times6=475{,}200$ sq. ft., or about 10 acres of surface of the embankment when passing only once on the same spot, or 5 acres if passing twice, and so on. The cost of the work is given by the daily expenses of hiring a team of horses, including the wages of the driver, which, according to the locality, may vary from \$3.50 to \$5.00, and dividing this quantity by the total amount of earth compressed in a day, given either in cubic yards, or in square yards of the surface of the embankment.

Rollers for compressing the earth are also made of very large dimensions and are operated by steam. Since these weigh several tons, it is dangerous to have them run on newly formed embankments, except in case the roads have either city or national importance.

The shrinkage of the earth in the embankments can be also prevented by wetting well the earths while the embankments are constructed. Especially if the work is done in the dry season water will have the same effect as rain. It will carry down the

small particles of material to fill in the voids contained in the whole mass. The smaller the number of voids left the more insensible will be the shrinkage of the embankment after it has been constructed.

When the earthworks are nearly completed, the cuts made, and the embankments constructed, it is necessary to reduce the bed of the road and the slopes to a smooth surface. This work is usually done by means of a shovel, and all the projections removed and the materials used in filling up the ruts and all cavities along the platform of the road. In portions of the road, through trenches, the earth removed is carried away, but the earth removed for leveling up the top of the embankment is thrown along the slope. The flat form of the road is reduced to a plane by beating it up with the flattened portion of the shovel, or otherwise with a piece of plank to which a handle is attached. This is raised up and let fall on top of the earth, and in this way it levels the earth and reduces it to a smooth surface. But the work of men is slow, since they cannot level up more than 250 sq. yds. a day, and with roads of great length this small item will amount to a great deal of money. Then it will be more convenient to grade the surface of the roads by machine. The graders used are those described on p. 103, and they are very efficient, and the amount of work that they can do in a day is easily calculated, depending upon the width of the blade and the distance traveled by the horses in a day. The cost of the running expenses is given by the cost of hiring a team of horses, including the wages of the driver and the wages of an operator, and dividing this sum by the total area graded in a day. When the surface of the road presents several irregularities the blade not only cuts, but carries away the material to be deposited where it is needed.

It is very convenient to have the slopes of the embankment sodded, but since such an operation will be very expensive it will not be allowed except in connection with the construction of the highways through cities. To preserve the slopes of the embankments it will be convenient to dig up the vegetable ground, and,

instead of using it in the fillings, to lay it aside to be used afterward, spreading it again on the slopes after the embankments have been constructed. This fertile vegetable ground will be seeded and wet, and the roots of the plants that will grow will form a cover to the slopes, preventing their sliding. Such an operation requires two different kinds of work: first laying aside the vegetable ground and then spreading this on the slopes. For the first operation is required from .2 to .3 of an hour's work for each square yard of surface, and for the spreading of the earth along the slopes, from .3 to .45; and, according to the quality of the soil for the two operations, will be required from ½ to ¾ of an hour per each square yard, and the cost of the two operations together will be from .051 to .075 k, when k is the daily wage of laborers and they work ten hours per day. These data are good for slopes 6 ft. high, but with higher slopes these quantities should be increased one-tenth for every 6 ft.

COST OF THE WORK.

The various implements for the excavation and hauling of the materials, together with the elements for calculating the cost of the unit of volume of the work, have been explained in the preceding chapters. Before closing this small review of earthworks it is necessary to devote a few words to the real cost of the work. There is no doubt that the most important item to be considered in the calculation of the real cost of the work is the cost of excavating and hauling the unit of volume of the earth, but there are other items which should not be forgotten, otherwise the contractor will find in the end a loss where he had expected to receive a fair profit.

The various items to be considered are as follows:

1st. The real cost of the work done either by men or by machines and hauled according to the various manners already explained.

2d. The general expenses, including superintendence, bookkeeping, traveling expenses, etc.

3d. The interest of the capital at hand, which is necessary for carrying out the work with success, as well as the premium for the bond given as guarantee of the contract.

4th. The accidents which are liable to happen to men and properties in the construction of the work, and for which the contractor may be held responsible.

5th. The profit of the contractor.

1st. In nearly every chapter dealing with the various methods of excavating and hauling the materials has been given the cost of the unit of volume of the work as deduced from the working expenses. But this is not the only item to be considered, since, according to what was explained in speaking of the work of the machines, the cost of the unit of volume of the work should be increased by some other quantities, as the interest of the capital invested in the machine, the repairing, and the sinking-fund.

Thus, for instance, the cost of removing the unit of volume of earth by means of a steam-shovel will be given by the daily running expenses of the machine divided by its efficiency. To this, however, should be added a quota for repairing, interest, and sinking-fund, obtained by dividing this sum by the total cubic yards of earth removed in a year by the same machine. These items will only represent the real cost of excavating the earth by means of the steam-shovel. In regard to the hauling the cost for the unit of volume is deduced in the same manner. If the earth is removed by trains running on standard-gauge tracks, the unit of cost is deduced from the daily running expenses divided by the hauled quantity in a day. Also, in this case, to this number a quota should be added for the repairing of the road, locomotives, and cars, interest of the capital invested in the railroad, including all the rolling-stock, besides the sinking-fund. This quota is given by these various items divided by the total quantity of the material hauled in a year. These final items, representing the cost of excavating one and the cost of hauling the other, will give the real cost of removing 1 cu. yd. of earth in the particular case considered.

The cost of the unit of volume thus obtained, multiplied by

the total quantity of the work as given by the calculation of the earthworks, will give the total amount of cost of the whole work.

2d. There are other expenses which, although not directly required for the excavation, yet are necessary for the direction of the work and to carry on the contract in the manner ordered by the specifications. These new expenses, usually known as general expenses, are of different kinds. Some are required for the direction of the work, and include all salaries and wages of the men who are directing the work; these are the engineers, superintendents, foremen, etc. To be included in the general expenses are those required for the administration, including timekeepers, bookkeepers, clerks, watchmen, etc., and others of general order, as office rent, stationery, correspondence, traveling expenses, illumination of trenches if the work is done in the cities or along country roads, etc. Since it would be too tedious and almost impossible to accurately calculate for each work all the general expenses according to the various items just mentioned, it is customary to lay aside a sum for such a purpose. This quantity, to be added to the cost of the work as given from paragraph 1, is variously calculated by the different authors, but it is not greater than one-tenth of the total cost previously found.

3d. The interest of the capital, which it is necessary to have at hand, so as to carry on the contract with a great success, and the premium to be paid to the company furnishing the bond, are important items to be considered in the calculation of the real cost of the work. It is a common practice for every party giving out contracts to require bonds from the contractor as a guarantee of the fulfilment of the conditions imposed upon him by the specifications. The total amount of the bond should not be, as a rule, greater than 20 per cent. of the total amount of the work, while the writer has knowledge of some contracts in which were required bonds amounting to 50 per cent. of the total cost of the work.

4. Excavations are dangerous works, and notwithstanding all the precautions which may be taken by engineers and contractors, accidents are liable to happen both to men and property. The workmen are the ones that, as a rule, make up the list of

the victims in any work, being continuously exposed, and it is the duty of the contractor to lay aside a sum for compensating these accidents, and such an amount should be taken into consideration in fixing the real cost of the work. On one section of the New York subway a contractor with a great political influence employed a lawyer so as to have him at hand in any accident, that he could gather evidence in order to demonstrate to the friendly judges that the accident was caused exclusively by the victim, and the contractor is only too generous when he refuses to sue him for damages. These are abominable means, and no gentleman will have recourse to them under any circumstances.

In removing the earth from its natural bed, the surrounding properties are liable to be damaged either on account of settlement of the ground if the earth is loose, or otherwise by the explosion when the soil is so hard to require blasting. To prevent landslides, the cut of the earth is shored, but even this does not arrest the settling of the soil when the soil is very loose, especially when the floor of the excavation is lower than the foundation of the houses, as will happen perhaps in Philadelphia in the construction of the subway, where the soil will be very close to the line of the buildings and their foundations are higher than the floor of the subway. Contractors must be ready to pay for these damages, and consequently it will be convenient to lay aside a sum to compensate them, and it should be deducted from the total benefit. The importance of such a sum depends upon the probabilities of the damages that may occur during the work. But in regard to the damages there is always a discussion on the party that is responsible for them, notwithstanding what the specifications call for, and what was agreed to in the contract. Thus, for instance, in the fourth section of the subway for the New York rapid transit for the damages to the surrounding properties on account of the great explosion caused by the wholesale storage of dynamite, as well as for the collapse of the houses, the city should have been held responsible. Consequently the contractors in such a case were

too lenient and too prompt to shelter the city engineer at their own expense.

5. Another important item to be considered in calculating the cost of the unit of volume of the work is the contractor's benefit. Until not long ago, and in some places continued still to-day, in this country contractors were only the agents of the corporations for which the works were done. These agents, called contractors, used to provide all the labor and material required for the work for a compensation of 5, 7, 10, or 15 per cent., according to their pull with the corporation. This is a very easy way of making money, and no wonder that so many ignorants who had the fortune of obtaining some one of these contracts became very rich, and were then and are still to-day regarded as great contractors.

Contractors, even according to our dictionary, are those who bargain for a specified sum to execute any work or enterprise of considerable magnitude. Contractors are running risks, must invest capital in the purchase of the various machines and implements for the execution of the work, and spend their time and intelligence in carrying out the work to a success, and consequently they are entitled to a benefit. It is a common practice to consider the contractor's benefit at 15 per cent. of the total amount of the work, but this may be either too large or too small according to the magnitude of the work. It will be too large a benefit when the work amounts to several million dollars, and it will be too small when it does not amount but to a few thousand dollars. Therefore, until a certain limit, the contractor's benefit should be inversely proportional to the total amount of the work.

Mr. Ponza, in his book "Prontuario di Stima," in pointing out the error of allowing contractors a fixed percentage of benefit, suggests a scale of benefits varying with the magnitude of the work in the following way:

Percentage	5	6	8	10	15	20
Amount of the work	$1,000,000	$500,000	$200,000	$50,000	$10,000	$1,000

These figures may be considered too small for American contractors, but the given percentage remaining fixed and taking the numbers representing the total amount of the work ten times greater than those given by Mr. Ponza, will have a standard scale of benefits to be considered fair and reasonable by any contractor in every country.

CHAPTER XXII.

EXAMPLES OF LARGE CANAL EXCAVATION WORKS.

In the construction of the many thousands of miles of railroads all over the world, it has been necessary to excavate an enormous quantity of earth, but the trenches and embankments were so narrow and the lines extended to such a great length that the work could be attacked at many points simultaneously. Besides, the earth was so easily handled that these works did not present any serious technical difficulty. But earthworks assumed a great importance in the construction of the large ship-canals built for national or international purposes. These magnificent works have been scientifically directed both in regard to the time and cost, and they stand now as monuments of engineering skill. Many of the machines already described have been invented or improved for the construction of these canals, and in their excavation ordinary earthwork has been elevated to a science.

In concluding this little review of earthworks, brief descriptions of the Suez, Chicago, Manchester, and Panama canals will be given as deduced from the works of Patton, Martelli and Stabilini, Hill, and the volumes of "Engineering" of London. The three former canals have been successfully completed and opened to traffic, the last one, after many financial difficulties, will be brought to completion by the United States Government.

The Suez Canal, cut through the isthmus connecting Asia with Africa, was constructed in the years 1857–69 under the direction of Mr. Ferdinand De Lesseps. The length of the canal is about 100 miles, and it connects Port Said on the Mediterranean with Suez on the Red Sea. The route of the canal deviates somewhat from a straight line on account of utilizing for over 20 miles

the interior lakes, called the Bitter Lakes. Two cross-sections were adopted for the canal; when it is excavated through sand or clay it has the following dimensions: width at water-surface 196 ft., at bottom 72 ft., and depth 26 ft. When the canal was dug through the lakes the cross-section was 327 ft. wide at the water-surface, 72 ft. at the bottom, and 26 ft. deep. The slopes were 2 to 1, except through water where they were 5 to 1.

The ground in general was flat and of very small elevation, being on the average not more than 6 ft. above the sea-level. At three points, viz., Chalons, Serapeum, and El Guisir, for a total length of 20 miles the elevations reached 50 and 60 ft., so that the cutting of deep trenches was required.

From Port Said and for a length of 40 miles the land was very flat; it was low and subjected to tides and to the floods of the Nile River. Its elevation was very close to the level of the sea. The soil, however, was compact, being composed of fine conglomerate sands and clays. The excavation of the canal through this low land was effected by means of sea-dredges, which dug their way and the removed material was deposited on both sides to form the levees on the edges of the canal. This manner of excavating canals through low lands by dredging has been ever since successfully employed in similar works of great magnitude.

In cutting trenches of great height, as that of El Guisir, the work at first was done by hand and the material removed by donkeys carrying on their sides mat baskets filled with earth, when it was not carried by laborers on baskets resting on their heads. From 25,000 to 30,000 men were employed at times, and at one place there were more than 1000 donkeys. When the forced labor system which prevailed at the beginning ceased, the engineers devised more rapid and economic schemes for the construction of the canal. To elevate the material from the bottom of the canal to the levees the flying wheelbarrow was used. Sometimes it was a very convenient device, but it was soon abandoned. Better results were obtained from the Couvreux excavating machine, especially constructed by Mr. Couvreux on the

principle of the sea-dredge. It was a continuous digging-machine of the ladder type, excavating the earth downward by means of numerous steel buckets connected to two endless chains and moved by a revolving drum of an engine. The excavated material was hauled away on trains running along the different planes of the cuts of the trench. In some other cases the earth was hauled away on cars pulled by chains moved by a fixed engine. The introduction of these machines greatly hastened the completion of the canal, so that the total amount of the work done in the last four years was three times greater than the work which had been done in the preceding eight years.

The total amount of earth excavated was 74,000,000 cubic meters, and the cost of the canal exceeded $100,000,000. Like any other great project, the excavation of the Suez Canal met with great opposition of various sorts. It was predicted that the canal once excavated would be soon filled up with sand and silt; that the Bitter Lakes would also become deposits of salt, and that no vessel would risk navigating the canal; but all these objections have utterly failed. The technical and even the worse financial difficulties of the enterprise which at times have seriously threatened the success of the operation were happily overcome. The large number of vessels passing every year through the canal already require it to be widened in order to meet the needs of commerce; the fact that the traveling distance to India has been shortened over thirty days stands now as the crowning glory of the great genius of De Lesseps.

Another important engineering work of more recent date than the Suez Canal, and which also involved an enormous amount of earth and rock excavation, was the Manchester Ship Canal, constructed in the years 1887–1893. The city of Manchester in England is world-famed for its industries and has been so for many years past, since it was already renowned for its industries during the reign of Edward VI. Being an inland city, it lacked convenient communication with the sea for the transportation of both the raw materials and products of the factories, and since the year 1822 was felt the necessity of a canal in which could

easily pass the largest vessels; landing their cargos in the heart of the city. But, with the introduction of railroads, the necessity of having easy communication was satisfied for awhile until with the wonderful development of the city the project of a large canal called itself again to the attention of the authorities in the year 1877. It was then carefully studied in all its details and the work began on Nov. 11, 1887.

The Manchester Ship Canal, 35½ miles long, begins at Eastham, near and opposite Liverpool on the estuary of the Mersey River and ends at Mode wheel in the city of Manchester. The total length of the canal can be divided into three sections, the first between Eastham and Runcorn following the left shore of the estuary; the second between Runcorn and Latchford is a canal, and the third between Latchford and Manchester is an improvement on the river Mersey. The minimum depth of the canal is 26 ft., and the width varies; for the portion between Manchester and Barton the bottom width is 170 ft.; from Barton to Eastham the bottom width is 120 ft. and the top width is 172 ft.

The canal is provided with several large locks both at the extremes and along the line, and passing through them the vessels may be raised to a height of 60.5 ft. It is a splendid example of a navigable canal reaching high elevations. Passing through a populated district it is crossed continuously by roads and railroads which required the construction of numerous drawbridges. The locks, bridges, and the arrangements for opening the locks are very interesting from an engineering point of view, but do not enter, however, into the limits of this book, and simply an account of the excavation of the canal will be given here.

Notwithstanding in the excavation of the Suez Canal the convenience of excavating low lands by means of sea-dredges which cut their way while digging the canal was clearly demonstrated, yet at Manchester the work began with the excavation of the earth in a dry state. It was only in the year 1890, after a freshet had broken the levees separating the bottom of the canal from the river, that it was deemed desirable to excavate the canal by dredging. Since then ten powerful dredges were employed in

this work, one of them, the "Manchester," having a capacity of 850 tons per hour. Only 3,000,000 cu. yds. were excavated by dredging, but the remaining 50,000,000 were dug by continuous or intermittent excavators.

For the excavation of the earth were employed 97 excavators, and the material was hauled away by 173 locomotives and 6300 cars running on standard-gauge tracks which were located either on the bottom or alongside the edges of the canal. The principal machines employed were of two different types, the steam-shovel, or navvy and the continuous down-digging machine.

The steam-shovels employed were of-different patterns and sizes. The Dunbar & Burton navvy, illustrated on p. 122, was the most extensively employed machine in this work. Its efficiency was to excavate and load about 1000 cu. yds. of earth per day at a cost varying between $18 and $20, including the wages of a crew of 12 or 14 men for the service of the machine and tracks. The cost of this machine was $5500. Another type of steam-shovel employed in the construction of the canal was the Wilson, which, although much lighter than the Dunbar & Burton, offered some advantages on account of being mounted as a locomotive crane, and, consequently, it could swing to a full circle, excavating the earth in every direction. Its capacity in a very loose soil amounted to 600 cu. yds. per day at a cost of $18, including the wages of a crew of 14 men. Among the steam-shovels should be mentioned the Whitaker intermittent excavator, which was more economical than the two previous types, since its cost was only $4000, but the capacity of the machine was somewhat less; it could not excavate more than 500 cu. yds. of earth per day. The great advantage of this machine was that it could work at will as a crane or an excavator, since the digging apparatus consisted of a grabbing-bucket which could be easily applied and removed.

More powerful than the steam-shovel or grabbing-bucket apparatus were the continuous digging-machines. These were of two different patterns, the French and the German. The downward continuous excavators, of French construction, were

built on the same principle as the Satre machine, illustrated on p. 107. The greatest efficiency obtained from this machine was 2236 cu. yds. in a ten-hour day's work, while the average quantity of earth excavated was 1490 cu. yds. per day at a cost of only $15. The excavator of the German type, built by the Lübecker Machinenbau Gesellschaft of Lübeck, Germany, was similar to the one of French construction, the only difference being that the roof covering the engine and boiler was very wide. The machine stands on three rails, leaving in the center room enough for the track of the cars which are loaded with the excavated materials. Such an arrangement increases the solidity of the machine at work and it is handled easier, although its weight was only 70 tons, while that of French construction was 80 tons. The capacity of the German down-digging machine was 1400 cu. yds. per day at a cost of $15.

Another important engineering work constructed in the last few years, which necessitated the excavation of a very large quantity of earth and rock, was the Chicago Drainage Canal. The city was drained by the narrow stream known as Chicago River, which emptied into Lake Michigan. With the increased population of the city the quantity of sewage increased, and the Chicago River became soon a center of infection. Since the water of Lake Michigan was used as the only supply for the city, it was deemed too dangerous to have the lake continue to perform the double duties of providing the pure water and receiving the sewage. Long ago it was found convenient to lift the water of the Chicago River and convey it into the Illinois and Michigan Canal, from where it found its way into the rivers beyond and ultimately into the Mississippi. But during freshets, when the floods disarranged the lifting-machines, the danger remained just the same as before. To solve the problem in a permanent way it was proposed to open a large canal connecting Lake Michigan with the Illinois River, and to construct the canal of such dimensions as to be used not only for drainage purposes but also for navigation after the necessary connections were made. This canal has assumed a national importance, since it is a part of the

great waterway connecting the Great Lakes of America with the Mississippi River and by it with the Gulf of Mexico—a waterway which will revolutionize perhaps American commerce, especially after the opening of the interoceanic Panama Canal.

The canal is 28 miles long between the south branch of the Chicago River near Robey Street to Lockport, and it runs almost in a straight line. The cross-section adopted was of two different types, varying with the quality of the soil through which it was excavated. When rock was encountered the cross-section was practically a rectangle 160 ft. wide at the bottom, 162 ft. wide on top, and 22 ft. deep. When, instead, the canal was cut through loose soil, a trapezoidal cross-section was adopted, having a bottom width of 202 ft. and side-slopes both above and below the water-surface of 2 to 1. The depth of low water was kept at 22 ft., and the canal had a given inclination of 1 in 40,000, corresponding to the flowing velocity of water of nearly 2 ft. per second through earth, and a fall of 1 in 20,000, corresponding to a velocity of water of nearly 3 ft. per second through rock.

Nearly 40,000,000 cu. yds. of materials were excavated, of which 12,330,000 were rock and 27,642,000 earth. But the excavation proper did not present any technical difficulty on account of being only 35 ft. deep on the average, and the excavated materials were deposited in spoil-banks alongside the edges of the canal. The work was divided into 28 sections of about 1 mile each, and the work was done by different contractors, who employed different machines, both for excavation and hauling purposes, some of which were especially designed and constructed for this work, while others were here applied for the first time in public works. The work on the canal began in July, 1892, and was completed in the year 1897.

The great importance that machines had in the construction of the canal can be easily deduced from the fact that at a period of usual activity the amount of plant employed along the line was considered to be as follows:

Steam-shovels	33
Steam- or air-pumps	85
" " " drills	243
" " " hoists	75
Channelers	88
Air-compressors	15
Locomotives	27
Cars	900
Dredges	27
Grading-machines	10
Steamboats	5
Dump-scows	17
Conveyors	62

Many of the machines described in other parts of this book have been employed or specially constructed for this work. In the excavation through rock the channeling-machine, which had been used until then for quarrying purposes, was successfully used here and was for the first time employed in public works. For the excavation of earth the Vivian scraper was especially designed in order to excavate the earth with a simple and powerful device, utilizing the numerous cableways that were extensively used for hauling purposes.

On account of the favorable conditions of the work, which the material excavated in the bottom of the canal was deposited on the waste-banks alongside its edges, it was found convenient to employ different machines for hoisting and conveying the earths. These were of three different types—the steel derricks, the cableways, and the cantilever conveyors. Messrs. Smith and Eastman of Chicago, contractors for Section 14, employed derricks, some of them being fixed; others, instead, were of the traveling type. The latter were built on a platform resting on a turntable, the whole being carried on a shifting track. The engine and boiler were located on the platform. The mast was 100 ft. high, and two booms were employed on each derrick whose length was 164 ft. and 155 ft. respectively. Both the booms and the mast

were of steel reinforced with crosspieces and wire ropes. The hoisting-engine was provided with four drums, two for each boom, the arrangement being such that each boom handled two skips—one depending from the end, and the other at some distance from it. The tackle was cleverly arranged, so that all the operations of lowering to the canal-bed and hoisting and tipping the skip were performed by the engineer and in a regular sequence. The operation was continuous, because when two of the skips from one boom were being loaded, the others on the opposite boom were being discharged, and on its being swung round, the operations were reversed. The derricks were placed in pairs on opposite banks in such a way as to command the whole width of the working section. From 120 to 450 cu. yds. of earth were handled with these derricks in a ten-hour day's work.

The Lidgerwood movable cableways were the hoisting- and conveying-machines extensively used in the construction of the Chicago Drainage Canal. It was in this work that the movable cableways were employed, and they have fully demonstrated that they are very valuable machines in the excavation of large canals. The tail-tower was mounted on a car running along the edge of the canal, while the tracks for the head-tower were placed behind the waste-bank. Since the total depth of the excavation of the canal was divided into three benches following each other at some distance, so each front was served by a cableway, and consequently they worked in batteries of three cableways each. In connection with the movable cableways was devised the aerial dump which was invented by Mr. Charles Locker and which is already described on p. 239.

The cantilever conveyors used for hoisting and conveying the materials from the bottom of the canal to the spoil-banks were the Brown machines described on p. 205. The tracks upon which were running the platforms supporting the tower to which the cantilever was fixed were placed near the edge of the canal. The Brown conveyors were working in batteries in the same way as the movable cableways, each one of them serving the work of one bench, and they were moved as the work advanced.

Mr. Patton says that there has been considerable competition between the manufacturers of the two machines. It was admitted that the cantilever was capable of handling a greater quantity of material in a day, but owing to its greater cost it was claimed that the cableways handle the materials more economically.

The interoceanic canal of Panama, still under construction through the narrow isthmus which divides South from Central America, has presented so many difficulties that the work has been abandoned many times and many times taken up again. After it brought financial ruin to thousands of families, sorrows to the promotors and engineers, and caused a scandal in which were involved the most prominent men of France at that time, its success is now assured, since it will be completed by the United States Government. All the trouble caused by the failure of the enterprise has been wrongly attributed to Mr. De Lesseps, who acted perhaps in too good faith, relying on unworthy men, and was misled and robbed by politicians. But it cannot be said that he underestimated the magnitude of the work, that no preliminary survey was made before the work began, and that he did not accurately study the particular conditions of the work, especially in regard to the disposal of water during the rainy seasons. The financial failure was chiefly due to the enormous prices paid in salaries and wages, especially at the beginning of the work, to the costly and high-priced plant required for the work, and to the floods which, during the rainy season, often in an hour destroyed the work of many months and worth millions of dollars.

As usually happens in any other great enterprise, also the Panama Canal as projected by De Lesseps was severely criticized by many engineers. When, after hundreds of millions of dollars were spent, it was realized that the work was still far from being completed, people began to listen to the critics and the original plans were modified. Mr. De Lesseps, following the advice of an International Committee which met in Paris in the year 1878, proposed to build an open sea-level canal, in which the steamers from one ocean could go through and enter the other ocean without the necessity of stopping or being lifted in their course. The

plans were afterward modified so as to have a high, level canal with a series of locks. Such a change was suggested in order to greatly reduce the enormous quantity of excavation which still remained to be done for the construction of the sea-level canal. This method was adopted as a scheme to complete the canal with the limited means upon which the company could rely, especially after the great financial troubles in which it had been involved. For so many years the work has proceeded slowly along this line. But now that the United States Government will complete the canal, it will be convenient to broadly discuss the question of the superiority of the high-level over the sea-level canal. A few million dollars more or less does not make any difference with the United States Government, and now that the cost of the canal is only a question of secondary importance, it will be convenient to take up again the question and see how wrong were Lesseps and the members of the International Committee who recommended a sea-level canal.

According to the original project, which the writer hopes that the United States Government will examine again before proceeding with the work, the canal was 43.54 miles long, including 2.48 miles of breakwater and approaches and 46 miles of inland canal. It begins in Simon's Bay near the city of Colon or Aspinwall on the Atlantic Ocean and ends near the city of Panama on the Pacific. The minimum distance between these two cities is only 60 kilometers, but the canal was projected with a longer route in order to take advantage of the two rivers, the Chagres and Rio Grande, which descend toward the two oceans from the ridge of mountains which run along the isthmus and in a direction perpendicular to the proposed line of the canal. The International Committee fixed the depth of the canal at 27.8 ft. with a bottom width of 72 ft., the slopes being fixed according to the quality of the soil encountered, but the width at the top of the water was to be 131 ft.

The work was divided into five sections, whose lengths and amount of material to be excavated are given in the following table:

Number.	Length in Miles.	Quantity of Cubic Yards.
1	16.33	32,500,000
2	10.95	31,200,000
3	6.00	58,500,000
4	2.10	35,100,000
5	8.16	18,200,000
		175,500,000

The first section begins at the extreme of the canal on the Atlantic Ocean near the city of Colon, and follows the northern shores of Simon's Bay for nearly 3.1 miles. This portion of the canal is cut through low marshy lands, chiefly composed of sand; its height varies from 3 to 6 ft. above sea-level. Then the canal turns westward toward the interior following the valley of the Chagres River whose course often intersects. For all the length of this section the land remains very low, and toward the interior the soil was found composed of loam, with the exception of three small portions in which rock was encountered. The rock was excavated by blasting, while nearly all the excavation in this section was effected by dredging. Dredges of different types were employed, and their efficiency varied from 5000 to 9000 cu. yds. per day. On account of the awful conditions of the climate, which prevented continuous work, the work obtained from the dredges never amounted to more than 4000 cu. yds. per day. The work in this section has been completed long ago.

The second section of the canal, 10.95 miles long, passes through lands which slightly increase in elevation. It begins at nearly 40 ft. above the level of the sea, and reaches a height of 145 ft. near the end of this section. The soil encountered is very resistent and compact, but it was easily excavated by the intermittent digging-machines of the steam-shovel type. Those employed in this section were of the Dunbar-Burton pattern, illustrated at p. 122, and the usual American Steam-shovel built by the Osgood Dredge Co. of Albany, N. Y. All together 19 machines were employed in this section, and the total amount of work obtained by them was 130,000 cu. yds. per month.

The third section, only 6 miles long, requires a total excavation of 58,000,000 cu. yds., and it necessitated the cutting of the Obispo and Emperador elevations with trenches 250 ft. deep. The Obispo hill is composed almost entirely of hard rock, alternated with strata of disintegrated rock. These strata of loose soil below the rock often caused the sliding of the surface soil, badly disarranging the work and producing accidents. In the Emperador's elevation the soil is almost composed of disintegrated rock, a soil which can be excavated by machine without recourse to blasting. In the construction of this section of the canal were employed 6 continuous digging-machines, 48 drilling-machines, and 66 cranes for hoisting the blasted rocks.

The fourth section of the canal includes the Culebra cut, which will be the deepest trench ever excavated in the world. It is 2.1 miles long with depths suddenly varying between 200 and 377 ft., and it will require the excavation of 35,100,000 cu. yds. of earth. The soil in this section, close to the surface, was composed of rock, alternated with strata of disintegrated rock, and the strata were very slippery. Such a fact, especially on beginning of the work, caused enormous trouble to the engineers. The cuts made in the day were often filled up again at night, and the large quantity of water flowing through the trenches during the rainy season often washed out the cuts, carrying away or undermining the heavy machines. Thirty-nine continuous excavators were employed in this section of the work, and the excavated material was hauled away by 36 locomotives and 1300 cars of 8 cu. yds. capacity, besides 600 tip-cars of the Decauville type of 2 cu. yds. each.

The fifth section of the canal, 8 miles long, extends from the Culebra hill to the Pacific Ocean, following the valley of the Rio Grande. The soil descends continuously toward the ocean, until in the last 6 miles it is only 10 ft. above sea-level. Both the quality of the soil and the conditions of the work were here similar to those encountered in the first section of the canal. Until the soil had a certain height it was excavated by means of the continuous digging-machine, but through the low portion of this sec-

tion the canal was dug by dredges. Eight continuous excavators, served by 16 locomotives, 360 cars of large capacity, 900 Decauville cars and 7 dredges, were employed in digging this section, which is already entirely excavated.

In connection with the construction of the canal other important works were required, one of the principal being the improvement of the Chagres River. It has been remarked that the route of the canal intersected several times the Chagres River, and it was then necessary to deviate its course. To prevent also that during the rainy season its water will obstruct the navigation, it was proposed to dig two parallel supplementary canals, one on each side of the main, so as to collect the whole amount of water flowing from the mountains. The total length of these canals would have been 27.28 miles, and they were projected with a cross-section 131 ft. wide and a depth varying from 13 to 16 ft., involving the excavation of millions of cubic yards of earth.

In the excavation of the Panama Canal at times were employed 13,000 men, of which 12,000 were workmen, and 1000 between foremen, superintendents, engineers, etc. As a rule, when an excavation is effected in any locality, bacteria spread in the air in such quantities as to affect the health not only of the laborers, but also that of the inhabitants living close by. For this reason are found symptoms of malaria near every excavation of some importance, and even in localities never affected before. But to excavate such an enormous amount of earth as was then required for the construction of the Panama Canal, and in a tropical region where many other diseases are encountered, was a hard proposition. The death-rate among the men employed in this work was something awful, being 7½ per cent. among the workmen and 6.4 per cent. among the employers. These numbers would have certainly been doubled if it were not for the strict sanitary measures adopted by the company in order to safeguard the health of its men, and for the enormous expenses it underwent to provide for the comfort of the men greatly improving the sanitary conditions of the locality. European workmen could not stand the climate and were decimated; the only ones

who could resist it in those regions came from Jamaica, but they were very slow in their work.

From the summary description of the Panama Canal as originally projected by Mr. De Lesseps, it is easily seen that the greatest difficulties are encountered in Sections 3 and 4 in the cutting of the Obispo, Emperador, and Culebra trenches. To avoid such an enormous quantity of excavation, and greatly reducing the cost of construction of the canal, it was suggested to have a sea-level canal through Sections 1, 2, and 5, and a high-level canal with 9 locks in Sections 3 and 4. With the feverish increasing of dimensions of the ocean vessels that are now considered almost small boats, those that were considered large steamers at the time the Panama Canal was begun, nobody could foresee the future progress of the interoceanic navigation, and a high-level canal with a series of locks would be found perhaps of great inconvenience to the enormous traffic of the Panama Canal.

Since this chapter was written, the author notes with pleasure, that Mr. John F. Wallace, Chief Engineer of the Panama Canal Commission, after six months' residence on the Isthmus, suggests a sea-level canal as the most practical one, thus corroborating the author's views.

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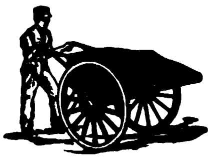
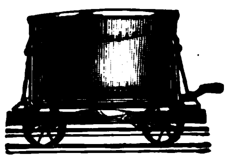


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